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SIMULATION OF THE COMPATIBILITY OF AN AIR CAPABLE SHIP AND A VTOL AIRCRAFT

George H. Daffer, et al

CADCOM, Incorporated

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AN AIR CAPABLE SHIP AND A VTOL AIRCRAFT

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by George H. Daffer and David F. Rogers

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13. ABSTRACT

An interactive computer simulation, LARC-I, has been designed to solve the non-linear equations of motion of a generalized VTOL aircraft taking off from or landing on the deck of a ship moving in an irregular or random seaway.

This version of LARC-I is limited to longitudinal motions, but is designed for eventual expansion to all degrees of freedom.

The LARC-I programs makes use of ship motion amplitudes and frequencies derived separately in a ship motions program, wherein the forcing functions of the seaway are based on a stochastic representation of the waves for any given sea state. The pitching and heaving motions of the ship are transmitted to the aircraft by a realistic simulation of the landing gear.

The program permits solution of an arbitrary maneuver, defined by a sequence of aircraft control changes, and composed of any number of segments of arbitrary length, in each of which the controls remain fixed.

The equations of motion for a generalized VTOL aircraft are particularized by adding a force and moment module for each specific aircraft. This version of LARC-I contains one such module for the CH-53A, D helicopters.

Dynamic validation with flight test data is considered excellent.

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SUMMARY

Project Description

This report describes the work accomplished by CADCOM, Inc., under ONR Contract N00014-72-C-0531, titled "Sea Control Ship/Aircraft Motions". The work was sponsored jointly by the Office of Naval Research and the Naval Air Systems Command.

The purpose of the project was to develop an analytical, computer-augmented, simulation to provide: (a) a launch/recovery effectiveness evaluation of ship-aircraft combinations under a variety of wind/wave and ship motion conditions, and (b) a specific effectiveness evaluation directed to a Sea Control Ship and the VTOL aircraft to be associated with its operation. The principal objective was the construction and subsequent evaluation of an accurate and representative simulation model.

It was established that certain limiting assumptions and simplifications would be necessary in order to make the development of a simulation possible under the given funding and time constraints and that the exercise of the model would be necessarily confined to two candidate sea control ships and two aircraft (CH-53 and Harrier).

The simulation package which was developed under the contract is called "LARC-I" (LAunch and Recovery Compatibility). LARC-I simulates the motion of an aircraft in an irregular seaway. Although the motions of the aircraft are confined to the x-z plane and those of the ship to heave, pitch and a forward motion, the LARC-I program is structured to allow an orderly modular expansion into a version which will simulate the motion in all six degrees of freedom, longitudinal and lateral.

The ship motions selected for the exercise of the model are parametric in nature and hence can represent the motions of a number of candidate air-capable ships. The aircraft used in the model exercise and generation of data was the CH-53D helicopter. During the performance period, CADCOM, ONR, and NAVAIR attempted to obtain data on the Harrier aircraft without success. Thus, the latter aircraft was eliminated from the computational phase of the project and, instead, additional data was generated for the CH-53D.

Conclusions

Data on the Harrier aircraft was received by CADCOM after the completion of this project, and it is included in this report (Appendix E) for reference purposes.

As a result of this work, the tentative conclusion has been reached that pitching and heaving platform motions will not limit normal take-off and recovery maneuvers of a VTOL aircraft of this type. Natural frequencies are too far apart to couple. Although there is an increase in control frequencies due to fuselage pitching moments, the required pilot response is within normal limits. Specifically:

a. For the ship motion conditions investigated, no serious stability problem occurred which would limit the take-off capability of the CH-53D helicopter. The static and dynamic stability margins of the aircraft are sufficient to allow safe take-off maneuvers with acceptable levels of pilot effort.

b. In no case were landing gear loads in excess of the design limit loads as given in References 6 and 7. (Note)

Recommendations

As a result of its experience with surveying the state of the art, developing the mathematical model, constructing the computer simulation, and applying LARC-I to realistic ship/aircraft operations, CADCOM makes the following recommendations:

a. Successful and realistic general use of the LARC simulation as an analytical tool in system analysis will require the extension of the program to all six degrees of freedom for both ship and aircraft. It is apparent from the results of the longitudinal motion studies that high-frequency cyclic response will result in roll forces which may couple with landing gear forces in the roll plane.

b. Real-time or quasi-real-time flight control should be added to the simulation to allow the operator to "fly" the model. His reference system would be provided by an interactive computer graphics display. In the present version, the model operates in short (5-8 second) control-fixed segments. In the proposed interactively controlled model, the

Note: Design limit loads - main gear: 21500#
(each gear - cond. T. D. L.)
nose gear: 17100#
(each gear - cond. L. L. 3 PT.)

high sampling rate control loop would allow adaptive control in a real-time mode which more accurately reflects pilot response.

c. Investigation of the mathematical representation of the random sea with the intention of resolving the problems discussed in Appendix D should be continued.

I. INTRODUCTION

Frequently the effect of the motion of a ship in moderate to heavy seas on the aircraft and/or the ship design and performance characteristics necessary for a high probability for a successful launch or recovery of aircraft have been given little consideration during the design phase. In fact, the design trade-offs between the ship and the aircraft performance characteristics are probably unknown to a large degree.

Recently the Sea Control Ship has emerged as a significant advancement in our defense posture. As presently conceived, the Sea Control Ship is a small, versatile combatant with significant air capability. If this new concept is to succeed, significant effort must be expended to insure that small ships can serve as adequate platforms for aircraft. Since the platforms on such ships will of necessity be smaller, the motions of those platforms will consequently be more severe than those of present aircraft carriers.

One of the first steps in the process of evaluating the air capable potential of candidate ship types and/or designs is to determine their seakeeping characteristics. Once the response of the candidate ship to various sea states is known, this information can be assessed together with the maneuverability and control characteristics of candidate aircraft to determine the potential as a Sea Control Ship or aircraft.

Using computer-aided analysis and interactive graphics, techniques it is possible to simulate the individual motions of both the aircraft and the ship and hence their relative motions. This leads to the ability to estimate the probability of a successful launch/recovery with existing aircraft from existing or proposed ships. In addition, it is possible to simulate the motion of proposed ship concepts and thus to determine the probability of a successful launch/recovery with existing or proposed aircraft.

In the following discussion, the motion of the ship is first discussed in Section II, then the motion of the aircraft in Section III, and finally the combined motion as used in the simulation as well as the simulation itself in Section IV.

II. SHIP MOTIONS

The characteristics of the ship which were used in this simulation are shown in Table II-1. Further details are given in detail in References 1 and 2. The determination of the ship response amplitude operator (RAO) was by means of the linear superposition theory described in References 1 through 3 except for the pitch RAO at a Froude number of 0.30. These responses were derived from model tests. The theoretical and experimental values are shown in Figure II-1.

TABLE II-1

MODEL M

PARAMETER	SHIP MODEL VALUES
LENGTH BETWEEN PERPENDICULARS LBP, FT	12.69
DRAFT AT ⊠ , FT	0.715
BLOCK COEFFICIENT	0.632
BEAM, FT	1.83
CENTER OF BUOYANCY, FT. AFT OF ⊠	0.208
STATIONS	10.33
CENTER OF FLOTATION, FT AFT OF ⊠	.324
STATIONS	10.83
RADIUS OF GYRATION/LBP, FT	0.256

The full scale length of the ship was assumed to be 630' LWL and LBP. The maximum speed of the vessel was assumed to be about 25 knots, corresponding to a Froude number

$$Fr = \frac{U}{\sqrt{gL}} = 0.30 \qquad \text{II-1}$$

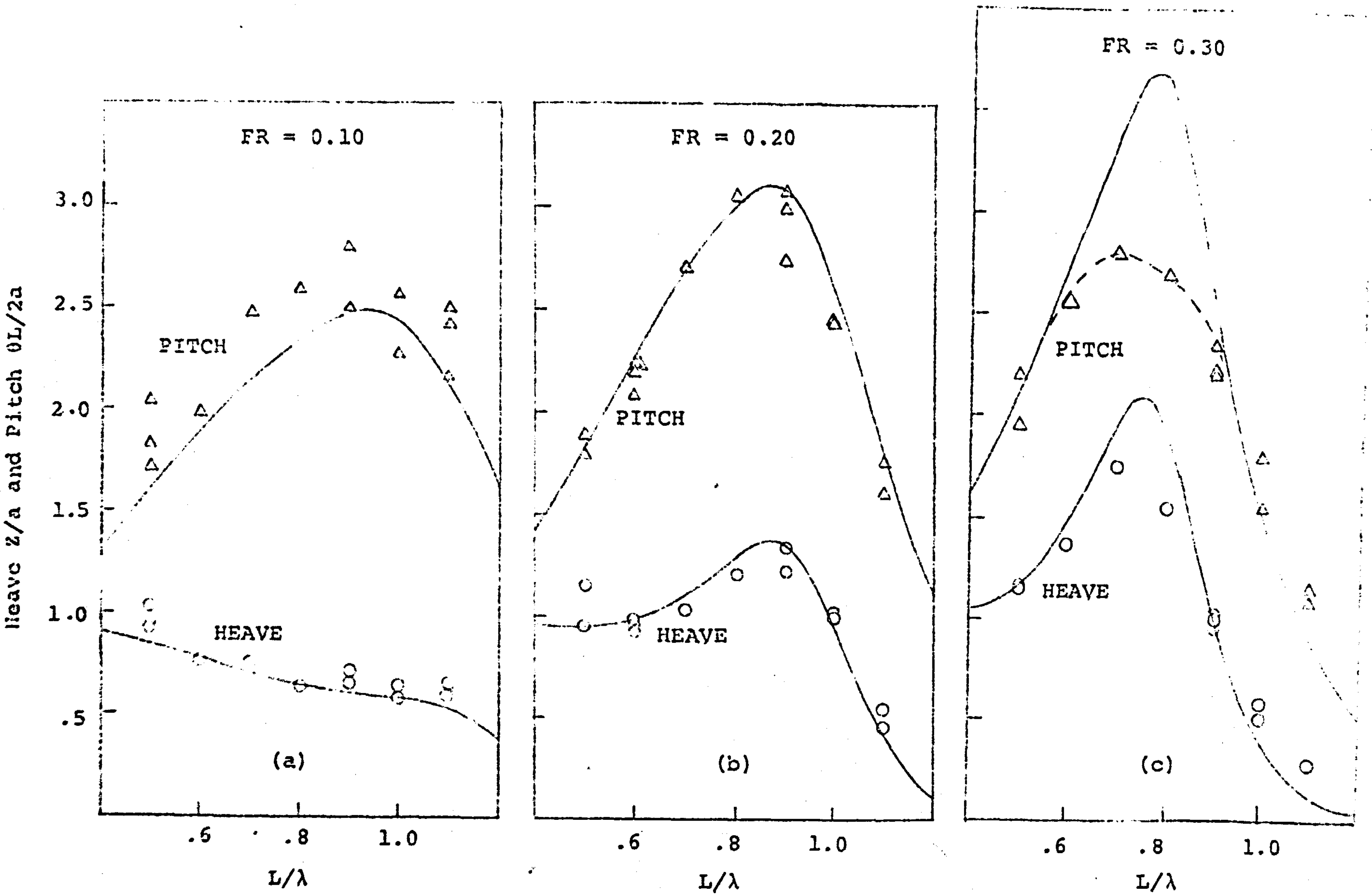

Figure II-1 Experimental and Theoretical Heave and Pitch Amplitudes for Model M Hull at FR. = 0.10, 0.20 and 0.30

The data shown in Figure II-1 are for Froude numbers of 0.10, 0.20 and 0.30, and for wave lengths ranging from $L/\lambda = 0.50$ to 1.10. In only one case were the experimental results substituted for the theoretical curve; the pitch response at $Fr = 0.30$. Except for this case, theory and experiment are in close agreement. At $Fr = 0.30$, the theory overestimates the pitch response by up to 38 percent. The authors of Ref. 1 attribute this to large "steady state" waves which may be expected at and above the design hull speed. The design speed for the Model M hull is about $Fr = 0.28$, or for a 630' ship, about 23.5 knots. Unless the interaction between the oscillatory motion and "steady state" Kelvin wave pattern is accounted for in the theory, strip theory may be expected to overestimate amplitudes in the speed regime where such waves affect the pitching response. For pitching amplitudes at $Fr = 0.30$ the dashed curve of Figure III-1c was used. This curve was coincident with the theoretical curve between $L/\lambda = 0.9$ to 1.2.

The Pierson-Moskowitz sea spectrum was used as the representation of the random seas. This spectrum is

$$S_\eta(\omega) = \frac{a g^2}{\omega^5} e^{-\frac{b}{h_{1/3}^2 \omega^4}} \qquad \text{II-2}$$

where $a = 0.0081$

$b = 33.56$

$h_{1/3}$ = significant wave height, ft.

ω = wave frequency, radians per second

g = acceleration of gravity, ft/sec^2

The spectral values for significant wave heights of 15, 20, 25 and 30 ft are shown in Figure II-2. This formula gives an approximation to real sea conditions which has been recommended by the 11th International Towing Tank Conference (1966) for use "when information on typical sea spectra is not available." The shapes of spectral curves derived from data collected in different sea locations and at different periods of the year show wide variations. In future studies, it is recommended that more representative data be used. At this stage (in this project) the Pierson-Moskowitz spectrum is adequate since the principal objective of the investigations described herein is the demonstration of the simulation model.

The curves of Figure II-2 approximate the spectra which would be derived from data collected at a stationary point. If the point were moving at a steady velocity in a straight line, the curves would be displaced to the right as shown in Figure II-3. The displaced curve in Figure II-3 is the 20-foot spectrum as it would appear to a ship moving at 25.3 knots or 42.8 FPS. To map the spectral data from the stationary $\omega - \chi$ plane (where ω is wave frequency and χ is wave heading) into the moving ω_e-χ_e plane, where ω_e is the frequency of encounter, where ω_e and ω are related by

$$\omega_e = \omega(1 + \frac{\omega U}{g} \cos \chi) \qquad \text{II-3}$$

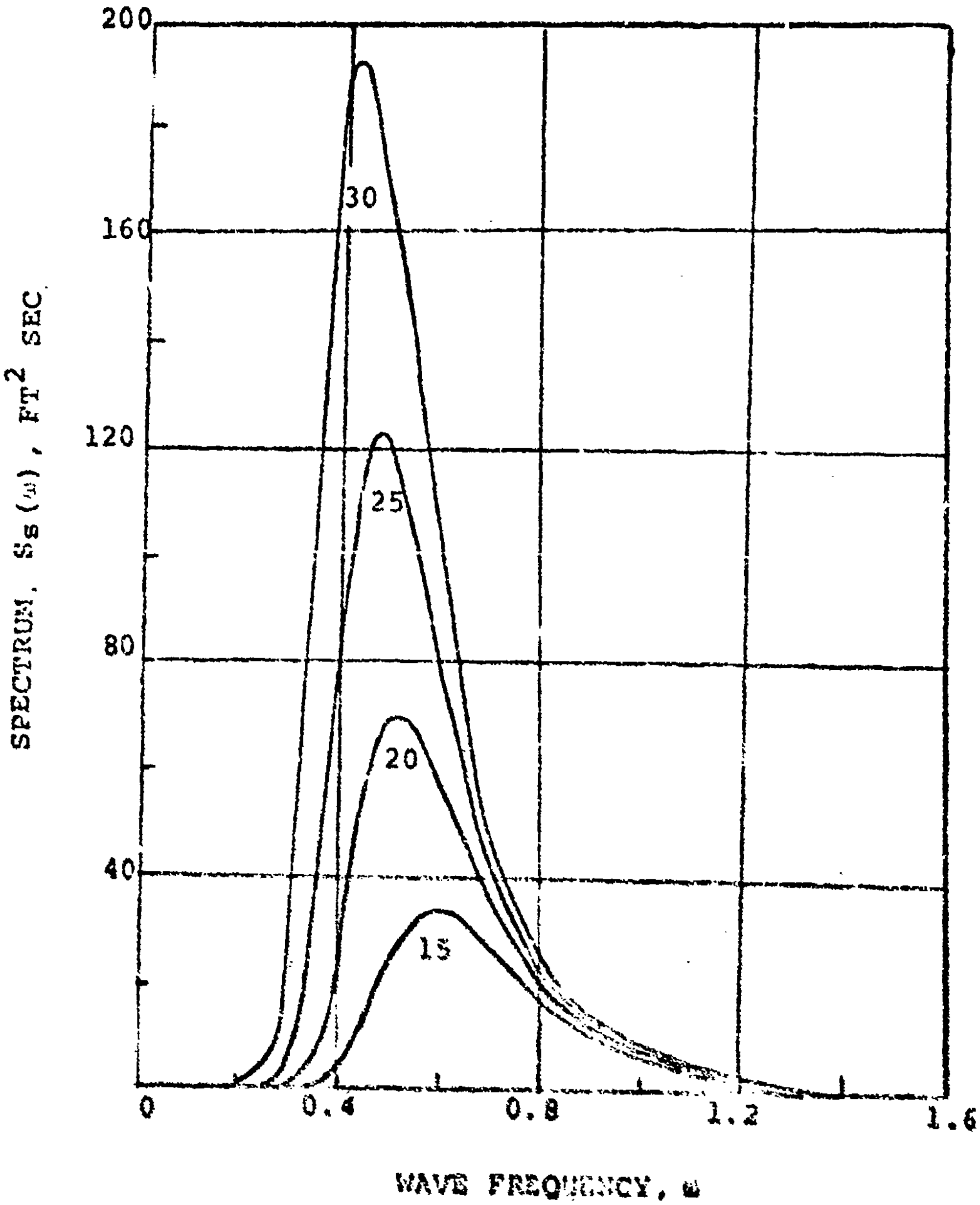

Figure II-2 The Pierson-Moskowitz Sea Spectrum for 15-, 20-, 25-, and 30-Feet Significant Wave Heights

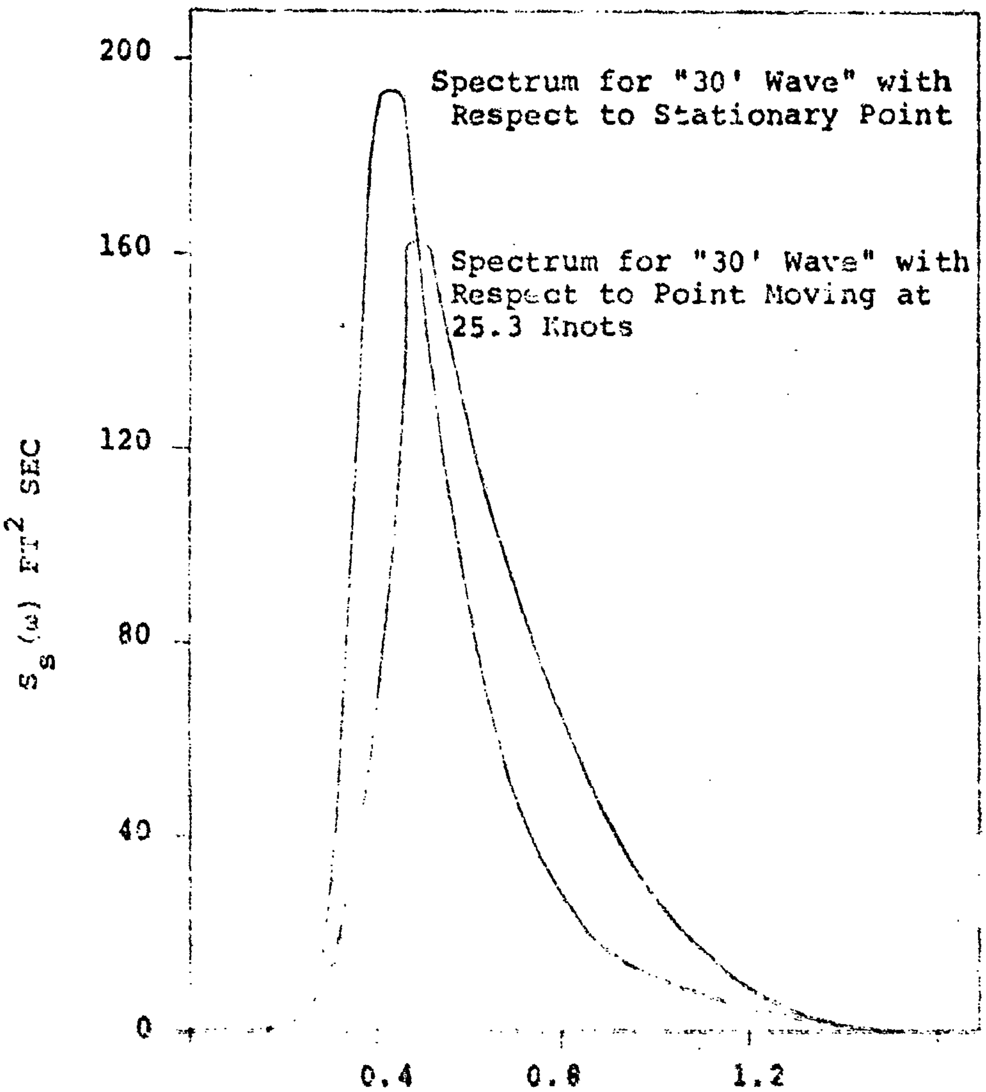

Figure II-3 Sea Spectra for Stationary and Moving Point - Significant Wave Height = 30 Ft.

it is necessary to make use of the Jacobean of the transformation

$$J \frac{\omega,\ \chi}{\omega_e,\chi_e} \triangleq \frac{\partial(\omega,\chi)}{\partial(\omega_e,\chi_e)} \triangleq \begin{vmatrix} \frac{\partial\omega}{\partial\omega_e} & \frac{\partial\omega}{\partial\chi_e} \\ \frac{\partial\chi}{\partial\omega_e} & \frac{\partial\chi}{\partial\chi_e} \end{vmatrix} \qquad \text{II-4}$$

For the head-on condition, where the ship is overtaking the waves and traveling in the same direction, the Jacobean is

$$\frac{1}{\left(1 + \frac{4\omega_e}{g} U\right)^{1/2}} \qquad \text{II-5}$$

Each ordinate of the "stationary" curve is multiplied by the above expression to give the corresponding ordinate of the transformed spectra, as it would appear to a moving ship (Reference 3).

Typical values of wave frequency, encounter frequencies and wave lengths for the 630' ship at Fr = 0.30 are shown in Table II-2 below.

TABLE II-2

L/λ	λ	ω_e	ω
.4	1575	.358	.265
.8	787	.507	.356
1.2	525	.621	.405

The wave length λ and the wave frequency ω are related by the equation

$$\omega_e = \left[5.118 \left(\frac{4\pi^2}{\lambda}\right) \right]^{1/2} \cong \frac{14.22}{\sqrt{\lambda}} \qquad \text{II-6}$$

For U = 42.3 fps, ω is given by

$$\omega \cong \frac{3}{8} \pm 1/2\sqrt{\frac{9}{16} + 3\omega_e} \qquad \text{II-7}$$

The transformed sea spectra and the ship's response amplitude operator squared are now multiplied ordinate-by-ordinate to obtain the response amplitude spectra for a given sea state and ship velocity. Examples are given in Figure II-4 for significant wave heights of 15 - 20 ft (sea state 6) and 25 - 30 ft (sea state 7), for the ship Model M moving at Fr = 0.30. Thus, the response energy spectrum as a function of encounter frequency ω_e is

$$S_R(\omega_e) = [R(\omega_e)]^2 \cdot S_S(\omega_e) \qquad \text{II-8}$$

The total energy of the response spectrum is by definition

$$E_R = \int_0^\infty S_R(\omega_e)\, d\omega_e \qquad \text{II-9}$$

and assuming a Rayleigh distribution of the maxima ("amplitudes") the following response values may be expressed:

the average "amplitude" $a_{av} = 1.253\sqrt{E_R}$ II-10

the significant "amplitude" (average of the 1/3 highest) $a_{1/3} = 2.000\sqrt{E_R}$

the "1/10 highest" (average of the 1/10 highest) $a_{1/10} = 2.546\sqrt{E_R}$

For a Froude number of 0.30 the heave and pitch motions induced at the ship's c.g. by irregular seas of given significant wave heights are shown in Table II-3.

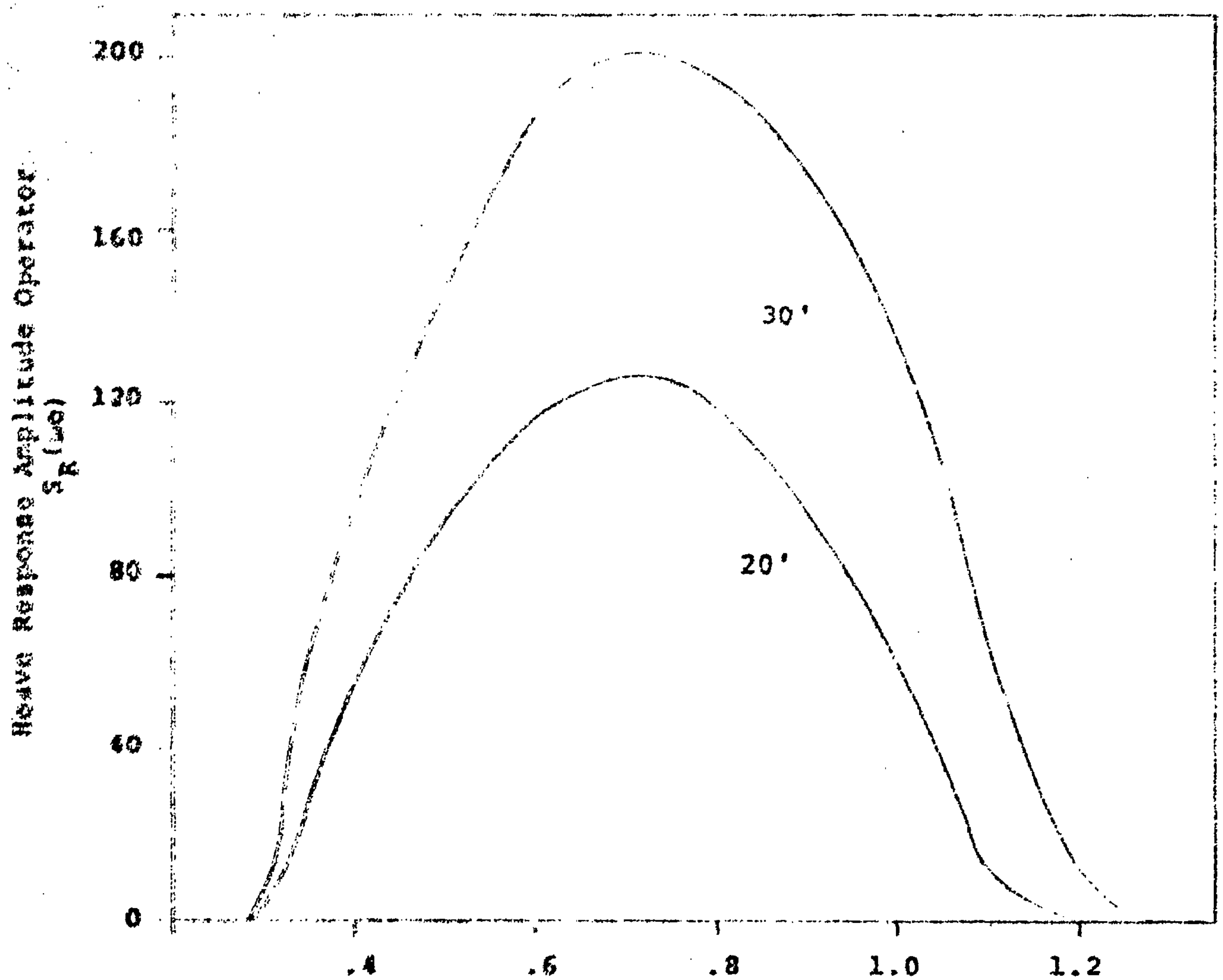

Figure II-4 Heave Response Amplitude Operator for Model M Hull in Two Sea States

TABLE II-3

SIGNIFICANT MOTIONS
(Avg. of 1/3 Highest)

SIGNIFICANT WAVE HEIGHT (FT.)	HEAVE AMPLITUDE (FT.)	PITCH AMPLITUDE (DEGREES)
15	8.932	2.113
20	11.207	3.163
25	14.514	4.321
30	18.035	5.492

The amplitudes shown in Table II-3 are those used in the program to calculate motions at the landing location.

The Pierson-Moskowitz Spectrum which was used in this determination of heave and pitch amplitudes expresses the energy in fully developed seas and it depends on only one parameter, the significant wave height $h_{1/3}$. With more parameters one could represent the sea spectra actually encountered which are for the most part not fully developed. Or, more accurately, a spectrum could be used, derived from actual wave data at a given location. This would provide the highest measure of accuracy but would necessarily apply only to conditions which may occur at that geographic location at that time of year. The Pierson-Moskowitz spectrum is used in this study because it is simple to apply and gives reasonable predictions.

Ordinarily, the simulation would determine the heave amplitude of any point other than the center of gravity by evaluation of the heave response spectrum

$$[R_{z,x}(\omega_e)]^2 = [R_{z,cg}(\omega_e)]^2 + \ell^2 (R_{\theta,cg}(\omega_e))^2 + 2\ell R_{z,cg}(\omega_e) R_{\theta,cg}(\omega_e) \operatorname{Cos}(\delta(\omega_e) - e(\omega_e)) \qquad \text{II-11}$$

where $R_{z,x}$ is the response amplitude operator in heave (z) at any point x

$R_{z,cg}$ is the RAO in heave at the c.g.

$R_{\theta,cg}$ is the RAO in pitch at the c.g.

ℓ is the distance from the c.g. to the point x,

ω_e is the encounter frequency and

δ, ε are the phase angles for pitch and heave respectively, both measuring the lead of the ship response with respect to the maximum wave elevation at the midship location.

The ship vertical displacement spectrum at any point other than the c.g. due to the combined motions of heave and pitch are determined from this expression in the same fashion as the heave and pitch separately at the c.g. That is:

$$S_{R_{z,x}}(\omega_e) = [R_{z,x}(\omega_e)]^2 \cdot S_s(\omega_e) \qquad \text{II-12}$$

and the significant response amplitude is

$$z_x(\omega_e) = 2.0 \left(\int_0^\infty S_{R_{z,x}}(\omega_e)\, d\omega_e \right)^{1/2} \qquad \text{II-13}$$

where

$S_{R_{z,x}}$ is the RAO in the z direction (vertical) at the point x due to pitch and heave at the c.g.

$Z_x(\omega_e)$ is the significant vertical displacement at the point x.

Although the results derived from this procedure are statistically correct, they are difficult to use because the motions due to pitch and heave are coupled in the resulting amplitude $Z_x(\omega_e)$. Use of this amplitude alone precludes the analysis of the effects of heave and pitch motions at the point x separately. It would be preferable to be able to use an expression of the form

$$Z'_x(\omega_e) = Z_{cg} \cos (\omega_e t - \delta) + \ell\theta_{cg} \cos (\omega_e t - \varepsilon) \qquad \text{II-14}$$

where Z'_x is the vertical displacement at x

Z_{cg} is the maximum vertical displacementto the cg

θ_{cg} is the maximum pitch displacement.

Or more conveniently

$$Z'_x(\omega) = Z_{cg} \cos(\omega'_e t) + \ell\theta_{cg} \cos (\omega'_e t - \delta')$$

$$\text{where } \omega'_e = \frac{\ell}{t} (\omega_e t - \delta) \qquad \text{II-15}$$

$$\text{and } \delta' = (\delta + \varepsilon)$$

At $\omega_e t = 0$ $\cos(\omega_e t) = 1$

$\sin(\omega_e t) = 0$

$$\text{and } Z'_x = Z_{cg} + \ell\theta_{cg} \sin \delta' \qquad \text{II-16}$$

If this is set equal to $Z_x(o)$, the coupled pitch/heave deflection at x, cos δ' and hence δ' can be determined.

An example of a calculation is shown below to illustrate the use of this method.

The ship motions program predicts the following motions at stations 10 (approximate c.g.) and 5 (157' forward) for a 30' wave condition

	STATION 10	STATION 5
VERTICAL	18.03'	28.56'
PITCH	5.49°	5.49°

$$(\delta') \cong \delta' \cong \frac{28.53 - 18.03}{157 \times 0.0958} = 0.698 \text{ RAD.} \qquad \text{II-17}$$

At first this result appears to contradict the phase relations predicted by the ship motions program. Figure II-5 shows these relations for the L/λ range from 0.4 to 1.2 for the Model M. The heave and pitch motions are everywhere out of phase by between 90° and 135°. However since the pitch always lags the heave by this amount, the vertical motions are additive and thus Equation II-15 is a very good approximation of the maximum absolute deflection when δ' is determined in this manner. The harmonic motion at the point x can be assumed very nearly equal to

$$\begin{aligned} Z_x &= Z_x' \cos(\omega_e t) \\ \theta_x &= \theta_{cg} \cos(\omega_e t) \end{aligned} \qquad \text{II-18}$$

with Z_x' determined by Eq. II-16 and with δ' calculated as in Eq. II-17 for the particular point 157' ahead of the

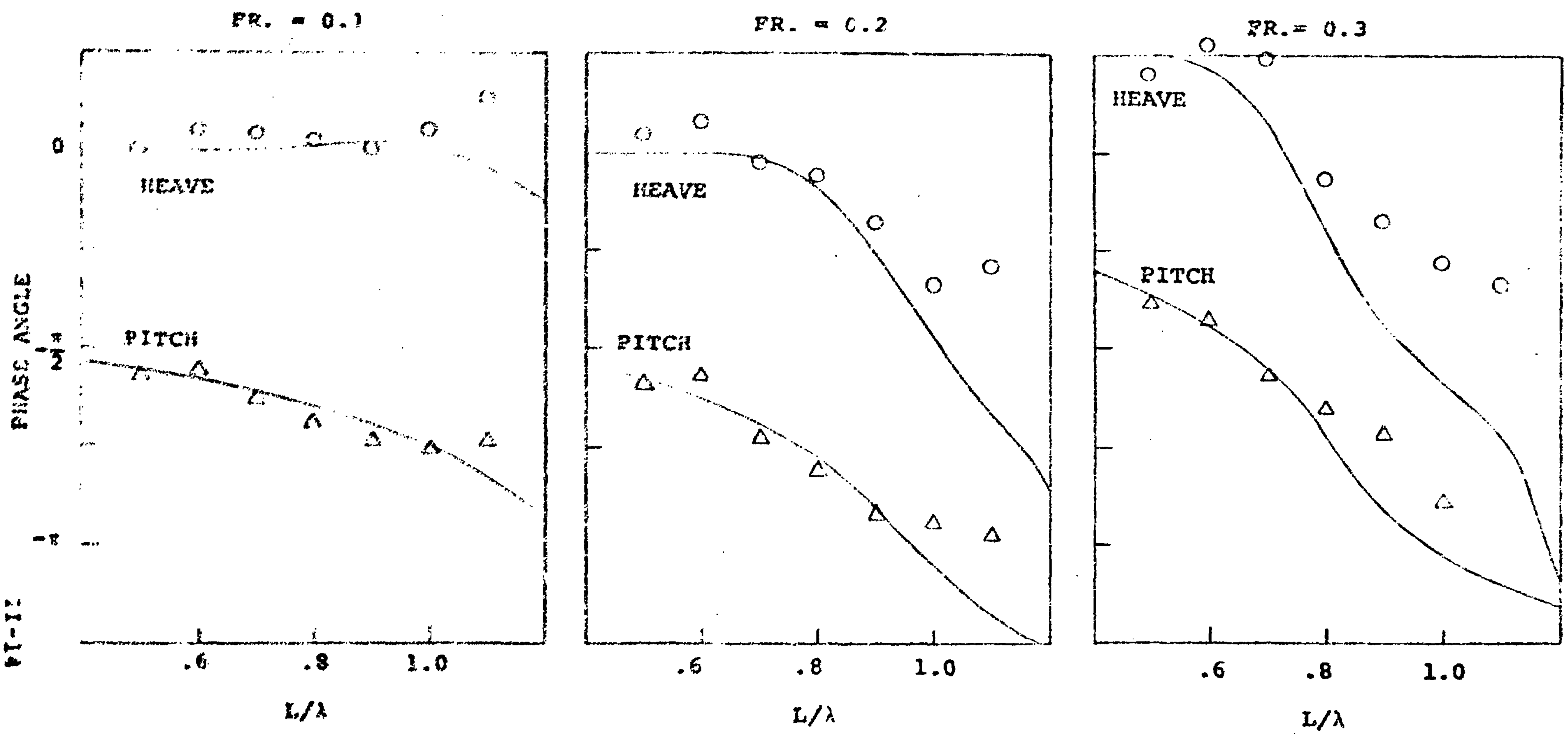

Figure II-5 Theoretical and Experimental Phase Angles for Model M cg, for a sea state spectrum based on a significant wave height $h_{1/3} = 30$ and a ship forward velocity of 25 knots.

The final problem, which must be solved in order to make the ship motions data useful in an investigation such as this, is the selection of a realistic value for ω_e. The procedure which has been used is to set the value of the encounter frequency equal to the ratio of the integrals of the amplitude and velocity response spectra in heave. (The difference in this value and the corresponding value for the pitch spectra is always very small, never greater than 0.02 rad/sec.) In effect, this is the ratio of the total energy of the response spectrum and the first moment of that spectrum, or

$$\omega_{e_{sig}} = \frac{\int^{\infty} \omega_e S_R(\omega_e)\, d\omega_e}{\int_0^{\infty} S_R\ (\omega_e) d\omega_e} \qquad \text{II-19}$$

(It makes no difference, incidentally, whether the sea spectrum S_s and the RAO are computed for wave frequencies, ω, or encounter frequencies, ω_e. That is to say the same values result when the sea spectrum $S_s(\omega)$ and RAO, $R(\omega)$, are transformed separately into the encounter frequency plane, and then multiplied, $(R(\omega_e))^2 \cdot S_s(\omega_e)$ to give the ship response spectrum $S_R\ (\omega_e)$, as when the response spectrum $S_R(\omega)$ transforms into the same plane without prior shifting of the component curves.)

Eq. II-19 gives the value of a weighted average where the weights are the squared amplitudes of the ship response associated with that particular frequency. Since the S_R curve does not by nature possess multiple maxima, Eq. II-19 computes a weighted value associated with the wave components (wave lengths) to which the ship can respond and to wave heights in the sea spectrum, $S_s(\omega_e)$, which possess significant energy content to excite the ship. Since wave length and wave height are independent, this is the only feasible way of associating these values. It is important to note that ω_e is not necessarily the most probable value. For example, if the ship response curve is flat through a range of frequencies, thus

$$\frac{dS_R(\omega_e)}{d\omega_e} = 0 \qquad \omega_{e_1} \leq \omega_e \leq \omega_{e_2}$$

then the value computed by Eq. II-19 will be between ω_{e_1} and ω_{e_2}; not necessarily midway between. In this case, very small changes in the amplitudes of $S_s(\omega_e)$ and $R(\omega_e)$, while not affecting the value of

$$E_s = \int S_s(\omega)d\omega$$

appreciably, are sufficient to effect the value of $\omega_{e_{sig}}$ to the extent that it may have any value between ω_{e_1} and ω_{e_2}. Since the total value of E_s has not been signficantly changed, all values of $\omega_{e_{sig}}$ in the range

ω_{e_1} to ω_{e_1} are nearly equally probable. Fortunately, the average ship acts like a narrow band filter and responds only to a narrow range of wave lengths approximately the same length as the ship (i.e. LWL $\pm$ 0.25 LWL). Since the period of most ship motions of interest in this study (say 10 - 15 seconds) is long in comparison to most motions of interest in the aircraft (1 - 5 seconds) the value of ω_e is not critical. This observation is further supported since Eq. II-19 assures us that the value computed lies in the range of nearly equal probability.

The values used in this study for a 30' wave condition, 630' ship moving at 25 knots into head seas were:

$$\text{heave amplitude} = 18.035$$

$$\text{velocity amplitude} = 12.320$$

$$\omega_{e_{SIG}} = 0.679$$

or since wave length $\lambda = 203/\omega^2$

$$\lambda_{SIG} = 440' = 0.70 \times \text{LWL}$$

Additional results are shown in Table II-4.

TABLE II-4

		SHIP CASE I	SHIP CASE II
V_s, SHIP VELOCITY, KNOTS		25	25
η_3, MAX. HEAVE AMPLITUDE[(1)], FT		18.035	11.207
η_5, MAX. PITCH AMPLITUDE[(1)], DEG		5.492	3.162
μ_e, NON DIMENSIONAL ENCOUNTER FREQ.[(2)]		3.45	3.45
δ', PHASE ANGLE OF PITCH WITH RESPECT TO HEAVE, RAD		.698	1.357
X_{i_s}, Z_{i_s} COORDINATES OF SHIP CG AT $t = 0$	FT	0	0
$X_{i_{LR}}$, $Z_{i_{LR}}$ COORDINATES OF LANDING AREA, $t = 0$	FT	(3)	(3)
$h_{1/3}$ SIGNIFICANT WAVE HEIGHT, FT		30	20
SS SEA STATE		7	6

(1) Significant (i.e., average of one-third highest) values. In the program, the parameter is the ratio of the "amplitude" η_3 to 1/2 the "height" $h_{1/3}$, thus 18.053/15=1.21.

(2) $\mu_e = \omega_e\sqrt{L/g}$ where L is the ship length.

(3) Three locations were studied: midships and ± 100' from midships, all 26.5' above W.L.

III. AIRCRAFT MOTIONS

As is well known, the equations of motion for an aircraft can be written in a variety of forms, each form more suitable to the solution of a specific problem (such as stability, response to gusts, control response, or automatic control design), and each form subject to advantages and limitations. In the past, most stability and control work has been accomplished with the linearized equations of small disturbance theory (Reference 4, section 4-14).

Since the stability of the aircraft being studied has already been demonstrated, stability for normal flight conditions is not a primary consideration. Thus, the force and moment equations themselves are used in this study. The principal advantages in using the force and moment equations lies in the ability to handle (a) large angular displacements (e.g. greater than 10°), (b) non-linear ground and air reactions, and (c) the coupling reactions between longitudinal and lateral forces.

Finally, the computer has removed most of the practical difficulties in the solution of the governing non-linear coupled equations.

The generalized equations of motion of an aircraft, which are used in this simulation, are given in Appendix B. These equations are identical to the equations presented in Reference 4, Section 4, except for the addition of the force and moment equation for the landing gear. They are generalized in the sense that they apply to a configuration consisting of any combination of the following components:

(a) Single rotor

(b) Two rotors in tandem rotor configuration

(c) Fuselage

(d) Horizontal tail

(e) Vertical tail

(f) Tail rotor

(g) Propellers or jet engine

(h) Lift engine or deflectable thrust

(i) Wings

(j) Various stabilization devices

For the present simulation, which is limited to the pitch plane, the governing equations of motion are:

The X-Force Equation:

$$X = (X)_{i} + (X)_{FUS} + (X)_{W} + (X)_{T} + (X)_{VT} + (X)_{TR_{i=1}} + \sum_{i=1}^{n} (X)_{P_i} - W \sin\theta - \frac{W}{g}(\dot{u}+\dot{\theta}\omega) = 0 \qquad \text{III-1}$$

where

$$(X)_F = L_F \sin(\alpha-\epsilon_F) - D_F \cos(\alpha-\epsilon_F)$$

$$(X)_{FUS} = L_{FUS}\sin(\alpha-\epsilon_{FUS}) - D_{FUS}\cos(\alpha-\epsilon_{FUS}) + F_{LG}$$

$$(X)_W = L_W \sin(\alpha-\epsilon_W) - D_W \cos(\alpha-\epsilon_W)$$

$$(X)_T = L_T \sin(\alpha-\epsilon_T) - D_T \cos(\alpha-\epsilon_T)$$

$$(X)_{VT} = -D_{VT}\cos(\alpha-\epsilon_{VT})$$

$$(X)_{TR} = -D_{TR}\cos(\alpha-\varepsilon_{TR})$$

$$(X)_{P_i} = T_{P_i}\cos i_{P_i} - N_{P_i}\sin i_{P_i}$$

The Z-Force Equation:

$$Z = (Z_F)+(Z)_{FUS}+(Z)_W+(Z_T)+(Z)_{VT}+(Z)_{TR_{i=1}}+ \sum_{i=1}^{n}(Z)_{P_i}+W\cos\theta-\frac{W}{g}(\dot{w}-\dot{\theta}u)=0 \qquad \text{III-2}$$

where

$$(Z)_F = -D_F\sin(\alpha-\varepsilon_F) + L_F\cos(\alpha-\varepsilon_F)$$

$$(Z)_{FUS} = -D_{FUS}\sin(\alpha\ \varepsilon_{FUS})+L_{FUS}\cos(\alpha-\varepsilon_{FUS})$$

$$(Z)_W = D_W\sin(\alpha-\varepsilon_W) + L_W\cos(\alpha-\varepsilon_W)$$

$$(Z)_T = -D_T\sin(\alpha-\varepsilon_T) + L_T\cos(\alpha-\varepsilon_T)$$

$$(Z)_{VT} = -D_V\sin(\alpha-\varepsilon_{VT})$$

$$(Z)_{TR} = -D_{TR}\sin(\alpha-\varepsilon_{TR})$$

$$(Z)_{P_i} = -T_{P_i}\sin i_{P_i} + N_{P_i}\cos i_{P_i}$$

The Pitching Moment Equation:

$$M = \sum_{i=1}^{n}(M)_i = \sum_{i=1}^{n}(X)_i\ell_{z_i} + (M_O)_i + M_I$$

and

$$M = (X)_F\ell_{z_F} - (Z_F)\ell_{x_F} + (X)_W\ell_{z_W} - (Z)_W\ell_{zW} + (X)_T\ell_{z_T} - (Z)_T\ell_{z_T} + (X)_{VT}\ell_{z_{VT}} - (Z)_{VT}\ell_{x_{VT}} + (X)_{TR}\ell_{z_{TR}} - (Z)_{TR}\ell_{x_{TR}} + \sum_{i=1}^{n}[(X)_{P_i}\ell_{z_{P_i}} - (Z)_{P_i}\ell_{x_{P_i}}] + M_{P_i} + M_{FUS} + M_{HUB_F} + Q_{TR} - \dot{q}I_{yy} = 0 \qquad \text{III-3}$$

TABLE III-1

SIGN CONVENTION

	POSITIVE
x	FWD
z	DOWN
θ	NOSE UP
$\dot{x}$	FWD
$\dot{z}$	DOWN
$\dot{\theta}$	NOSE UP
α	pos. nose up (cw rotation from wind vector to x-axis)
β	pos. if L.E. swash plate is down
γ	UP
$\epsilon_{FUS}, \epsilon_T$	pos. if increases local α
l_x	FWD of CG. (in pos x-direction)
l_z	BELOW CG. (in pos z-direction)

Forces and moments as shown in Figure III-1.

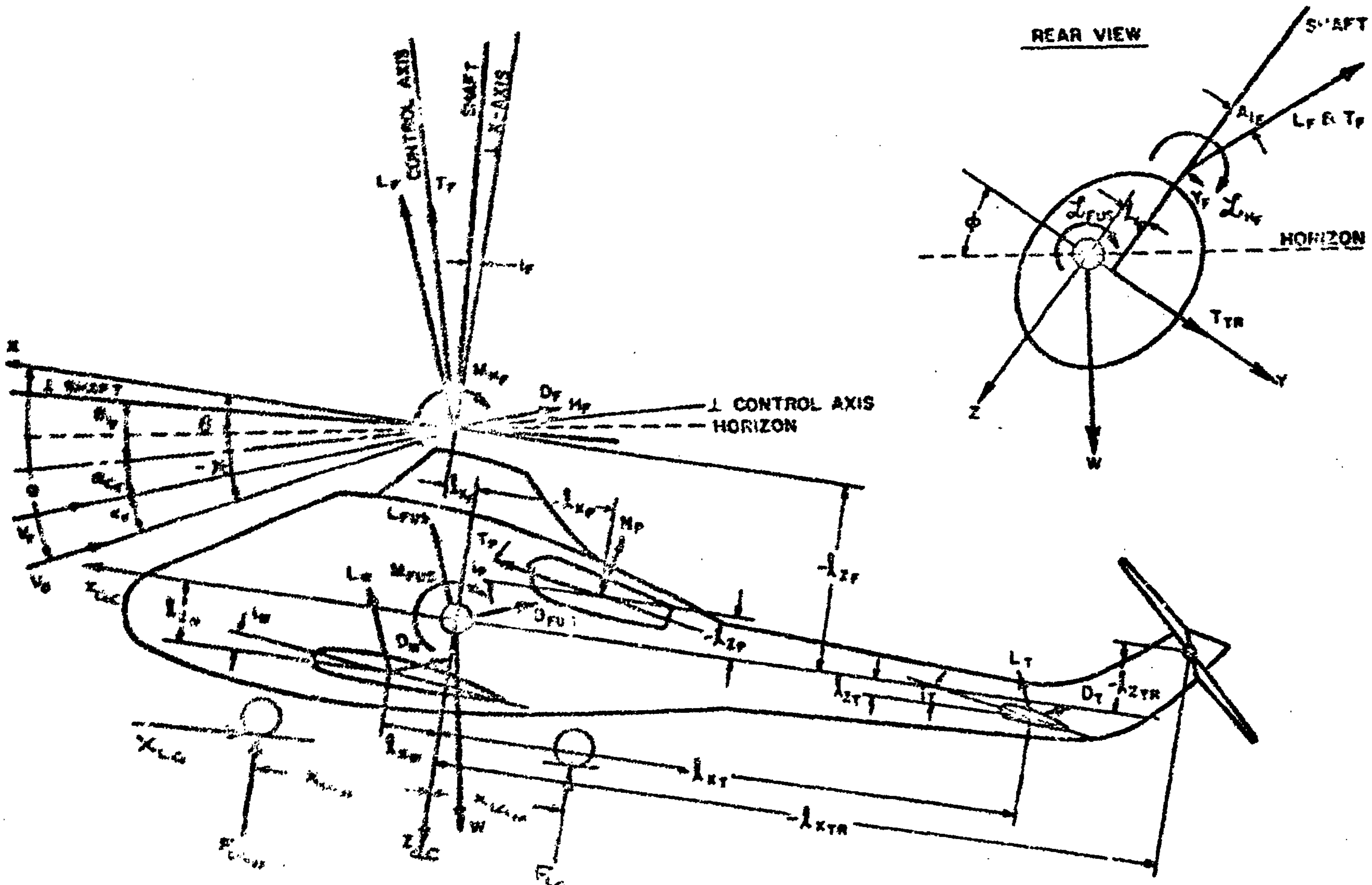

Figure III-1 AXIS SYSTEM AND SIGN CONVENTION where the notation is given in Figure III-1 and Appendix B. The sign conventions are given in Figure III-1 and Table III-1. Assuming that the external forces and moments are known, these equations represent three equations in the three unknowns u, w, and θ and can thus, in principle, be solved. In the present simulation this is accomplished numerically using a fourth-order Runge Kutta integration scheme.

The method of determining the forces and moments of the governing equations for the particular aircraft considered in this simulation, the CH-53D, is given below. Further information applicable to the CH-53D aircraft is given in Appendix C. These methods are considered in the following order:

Landing Gear Forces

Rotor Forces, Angle of Attack, and Engine Power

Rotor Hub Moment

Fuselage Forces and Moments

Tail Forces and Moments

Interference Angles

Automatic Flight Control System (AFCS)

The Ground Effect

III-1 Landing Gear Forces

(1) Pneumatic shock strut Isothermal compression is assumed. Maximum stroke on both gears is 12". In the following formula, stroke is measured from the fully

compressed position. The stroke vs. pressure characteristics (Ref. 7-9) for the landing gears are as follows:

		PRESSURE, psi	
STROKE		MAIN	NOSE
STATIC	2"	850	
67% EXT	8"		365
EXTENDED	12"	187	275

Nose Gear Determine cylinder length:

$$P_{67\%} L = P_e (L + 4)$$

$$365 L = 275 (L + 4)$$

$$L = 12.22\text{" from 67\% EXT.}$$

Pressure, fully compressed

$$P_c L_c = P_e L_e$$

$$P_c = \frac{P_e L_e}{L_c} = \frac{275 \times 16.22}{4.22} = 1060 \text{ psi}$$

Load at any stroke

$$\text{LOAD} = PA = \frac{P_c L_c A}{S + L_c}$$

$$= \frac{1060 \times 4.22 \times 19.36}{S + L_c}$$

$$= \frac{86600}{S + 4.22} \quad \text{PER STRUT}$$

III-4

$$= \frac{173200}{S + 4.22} \quad \text{TOTAL (2 STRUTS)}$$

MAIN GEAR Determine cylinder length:

$$P_s\ L = P_e\ (L + 10)$$

$$850\ L = 187\ (L + 10)$$

$$L = 2.825 \text{ from static}$$

$$= .825 \text{ from compressed.}$$

Pressure, fully compressed

$$P_e = \frac{P_s L_s}{L_c} = \frac{850 \times 2.825}{.825} = 2915 \text{ psi}$$

Load at any stroke

$$\text{LOAD} = \text{PA} = \frac{P_c L_c A}{S + L_c} = \frac{2915 \times .825 \times 19.36}{S + 0.825}$$

$$= \frac{46500}{S+0.825} \quad \text{PER STRUT}$$

$$= \frac{93000}{S+0.825} \quad \text{TOTAL (2 STRUTS)} \qquad \text{III-5}$$

In the simulation model all forces in the lateral plane are assumed to be zero, hence the load equations for both nose and main gear are multiplied by 2 to give total load.

(2) Damping Damping is provided by the restriction of the flow of oil through an orifice with a sharp edged entrance on the lower side, and a rounded entrance (radius = .78 x plate thickness) on the upper side. Damping is in both directions, adding to the pneumatic force as the strut is compressed and subtracting as it extends.

The properties of the oil used in the shock strut are not known and no information concerning damping characteristics of the shock strut is given in the reports listed among the references. For the purposes of this study, it was assumed that the oil had the following properties (at 60°F)

μ = 500 centipoises (absolute viscosity)

S = .88 (specific gravity)

Thus $\rho = .85 \times 62.4 = 55\ \#/ft^2$

$\mu = 500 \times 2.09 \times 10^{-5} \cong 10^{-2}$ slugs/ft-sec

R = Reynolds number

$= \frac{Vd_o\rho}{\mu}$ where d_o = orifice diameter

V = velocity through orifice

$d_o = 0.75"$

$d_1 = 4.122"$

In terms of piston speed V′

$$R = \left(\frac{4.122}{.75}\right)\left(\frac{4.122}{12}\right)\left(\frac{55}{10^{-2}}\right)V'$$
$$\cong 10^4\ V'$$

V' is the compression or extension rate of the shock strut and is equal to the sink or rebound rate (in ft/sec) of the aircraft. Values of V' for which the damping force is significant (say more than 1/10th the air compression force) are above one foot per second, hence the Reynolds number in all cases of interest is above 10^4. In the range $10^4 \leq R \leq 10^6$, the discharge coefficient C for a diameter ratio $d_o/d_1 = .75/4.122 = 0.18$ is approximately constant and equal to 0.6 (see Ref. 14). Solving the standard flow equation

$$q = C\ A_n\sqrt{\frac{2g\Delta P}{\rho}} \qquad \text{III-6}$$

for damping force (D.F.) = $\Delta P \times A_c$ (psi x in^2)

in terms of $q = V_c A_c$ (in/sec x in^2)

where V_c is the piston or stroke velocity, in/sec, for C = 0.60 and ρ = 55 #/ft^3 = .032 #/in^3

$$D.F = \frac{\rho A_c}{2g\ C^2} \left(\frac{A_c}{An}\right)^2 V_c^{\ 2}$$

$$= \frac{.032 \times 19.36}{2 \times 386.4 \times 0.60^2} \left(\frac{d_1}{d_o}\right)^2 V_c^{\ 2}$$

$$= \frac{.62}{278} \left(\frac{4.122}{.75}\right)^2 V_c^{\ 2}$$

$$= \frac{.062 \times 30.2}{278} V_c^{\ 2} = .067\ V_c^{\ 2} \quad (V_c \text{ in in/sec})$$

$$= 9.65\ V_c^{\ 2} \quad (V_c \text{ in ft/sec})$$

$$\cong 10\ V_c^{\ 2}$$

There is no mention of a metering pin in the available literature, except obliquely in Ref. 8. However, this extremely low value of the damping factor indicates that one must be present. In terms of the ratio r_{mn} of the metering pin diameter, d_m, to the orifice diameter, d_o, the damping factor can be written as:

$$D.F. = 10 \left[1 - r_{mn}^2\right]^{-1} V_c^2$$

$$= C_D\ V_c^2$$

where C_D is the damping constant and $r_{mn} = \frac{dm}{dn}$.

For practical values of r_{mn}, C_D has the following values:

r_{mn}	C_D
.9	52.7
.95	100
.975	200
.985	360

For a metering pin diameter $d_m = 0.950\ d_n$, the clearance in the orifice hole between the sides of the pin and the orifice edge is (1/2)(.050) (.75) = (.0250) (.75) = .01875", which is slightly larger than 1/64". In the simulation, the damping constant (C_D) was chosen to correspond to 100. Thus, for a sink (or rebound) speed of 10 fps, the damping force is D.F. = 100 x 100 = 10000# (or -10,000#).

Both the viscosity and density of the oil are functions of the temperatures. The variations in viscosity should have no effect. Although the variation is quite large, viscosity effects only the Reynolds number, which in turn effects the orifice coefficient C. But in the range of interest, C is a constant. Density is less affected by temperature, there being a drop of perhaps 10% as the temperature changes from 0 to 100°F, and in view of the other uncertainties of the damping force calculation, this can be ignored.

Usually, metering pins taper from the base to a point near the end where the pin flares into some sort of a bulb, so that maximum orifice constriction occurs at either end of the stroke. This variation was ignored.

Thus, for the present simulation, the damping force is assumed to be given by the expression:

$$\text{D.F.} = \pm\ 100\ V_c^2 \qquad \text{III-7}$$

The plus sign applies when the strut is extending, since the damping force is downward.

(3) Tire Forces In the interest of simplicity, tire forces are not included in this version of the simulation. The inclusion of the tire would add a degree of freedom to each landing gear. This assumption can be justified by noting that the work done by the tire is small in comparison to the work done by the shock strut. Further, the work done by the tire has a strong effect on the dynamics of the aircraft. Since the unsprung mass begins moving at a somewhat later time, the real effect on landing gear forces, as far as the aircraft is concerned, is to delay the build-up of forces during the landing. However, the overall effect is small in cases where the unsprung mass is small and hence can be ignored.

III-2 Rotor Forces, Angle of Attack and Engine Power

Assuming that the thrust is known, the following parameters can be determined:

(a) Thrust coefficient C_{T_R}

(b) Collective pitch $\theta_{.75}$ and λ for minimum profile drag

(c) Torque coefficient C_{Q_R} and Torque Q_R required

(d) Power required P_R

(e) Power ratio (PR) - required-to-available

(f) Rotor angle of attach α_c

(g) H - Force

(h) Rotor lift and drag.

The computations are accomplished in the following order:

a) <u>Thrust coefficient</u>

$$C_T = \frac{W\ (T_R/W)}{\pi R^2\ (\Omega R)^2} \qquad \text{III-8}$$

b) <u>Collective pitch setting for minimum torque</u>

If Eqs. 72 and 74 of Reference 13 are added, the resulting expression is the net torque at the rotor shaft and has the form:

$$C_Q = K_1\theta_o^2 + K_2\theta_o + K_3\lambda\theta_o + K_4\lambda^2 + K_5\lambda + K_6 \qquad \text{III-9}$$

where the coefficients K_i are lengthy expressions which are defined in sub-section 3. Eq. 69 of Ref. 12 gives the thrust coefficient C_T in terms of λ and θ_o:

$$\frac{C_T}{\sigma_a} = t_{3,1}\lambda + t_{3,2}\theta_o + t_{3,3}\ (\theta_o + \theta_t) \qquad \text{III-10}$$

θ_o is the blade pitch at the root (collective pitch) and θ_t is the blade twist. Since C_T is known, Eq. III-10 may be solved for λ which may be substituted in III-9. This yields a quadratic in θ_o. Taking the first derivative and setting it equal to zero gives:

$$\theta_o = \frac{D}{N} \qquad \text{III-11}$$

where $D = [a(t_{4,2} + t_{4,3}) - \delta_2(t_{5,6} + t_{5,7})] - \delta_1(t_{5,3} + t_{5,4})$

$$+ (at_{4,5} - \delta_2 t_{5,9})\theta_t + 2(at_{4,6} - \delta_2 t_{5,10}) \qquad \text{III-12}$$

and $N = 2\delta_2\ (t_{5,8} + t_{5,9} + t_{5,10}) - 2a\ (t_{4,4} + t_{4,5} + t_{4,6})$

$$+ \frac{t_{3,2} + t_{3,3}}{t_{3,1}}\ [\delta_2\ (t_{5,6} + t_{5,7}) - a\ (t_{4,2} + t_{4,3})]$$

III-13

In these expressions

t_{ij} are the Bailey coefficients, Ref. 13

δ_i are the coefficients in the section drag equation

$c_{d_o} = \delta_o + \delta_1\alpha_r + \delta_2\alpha_r^2$ (Ref. 4 - 12)

a is the slope of the section lift curve

and θ_t is the blade twist.

Since the second derivative of C_Q is positive for a given value of C_T, Eq. III-11gives the value of θ_o for minimum torque. With this value of θ_o, Eq. III-10 may be solved for λ.

c) Torque coefficient C_Q

The torque coefficient may be calculated by means of Eq. III-9 using the values of θ_o obtained from Eq. III-11, and λ from III-10. The coefficients of III-9 are

$$\left.\begin{aligned}
K_1 &= (\delta_2 t_{5,8} - at_{4,4}) + (\delta_2 t_{5,9} - at_{4,5}) + \delta_2\, t_{5,10} \\
K_2 &= \delta_1 t_{5,3} + \delta_1 t_{5,4} + (\delta_2 t_{5,9} - at_{4,5})\theta_t + 2at_{4,6} \\
K_3 &= (\delta_2 t_{5,6} - at_{4,2}) + (\delta_2 t_{5,7} - at_{4,3}) \\
K_4 &= (\delta_2 t_{5,5} - at_{4,1}) \\
K_5 &= \delta_1 t_{5,2} + (\delta_2 t_{5,7} - at_{4,3})\theta_t \\
K_6 &= \delta_o t_{5,1} + \delta_1 t_{5,4}\theta_t + \delta_2 t_{5,10}\theta_t^2
\end{aligned}\right\} \quad \text{III-9a}$$

Torque is given by the expression

$$Q_R = C_Q\ (\pi R^2 \rho\ (\Omega R)^2\ R) \qquad \text{III-14}$$

d) Power required $P_R = \dfrac{Q_R\Omega}{550}$ shp. III-15

Maximum power for the CH-53D, a function of temperature (°C), is taken from Figures 4.5 and 4.6 in Ref. 6.

$$\begin{aligned}
P_{max} &= 6432 \quad \text{shp} \quad t \le 15°C \\
&= 6858 - 29.1t \quad 15°C > t > 59°C \quad @\ 100\%\ Nf \\
&= 5140 \quad t \ge 59°C
\end{aligned} \qquad \text{III-16}$$

e) The rotor angle of attack

Eq. 70 of Ref. 12 yields:

$$\alpha_c = \text{arc tan}\left[\frac{\lambda}{\mu} + \frac{C_T}{2\mu(\mu^2+\lambda^2)^{1/2}}\right] \qquad \text{III-17}$$

f) The H Force The profile drag-lift ratio is expressed as

$$\left(\frac{D}{L}\right)_o = \frac{\sigma a}{2\mu}\left[\frac{\delta_o}{a} t_{6,1} + \frac{\delta_1}{a}\left(t_{6,2}\lambda + t_{6,3}\theta_{.75}\right) + \frac{\delta_2}{a}\left(t_{6,5}\lambda^2 + t_{6,6}\lambda\theta_{.75} + t_{6,8}\theta^2_{.75}\right)\right]$$

It is also equal to

$$\left(\frac{D}{L}\right)_o = \frac{H\cos\alpha_c - T\sin\alpha_c}{T\cos\alpha_c - H\sin\alpha_c}$$

Thus

$$H = \frac{-T(\sin\alpha_c + \frac{D}{L}\cos\alpha_c)}{\cos\alpha_c + \frac{D}{L}\sin\alpha_c} \qquad \text{III-18}$$

g) Rotor lift and drag The rotor lift and drag:

$$L_F = T\cos\alpha_c - H\sin\alpha_c \qquad \text{III-19}$$

$$D_F = H\cos\alpha_c - T\sin\alpha_c \qquad \text{III-20}$$

III-3 The Rotor Hub Moment

The moment due to flapping hinge offset is given in Ref. 5 (p. 49) as

$$M_H = K(a_1 - B_{1S}) - \left(\frac{ae}{12R}\right)\left(\frac{\dot{\theta}f}{\Omega}\right)\left[1 - \left(\frac{e}{R}\right)^3\right] \qquad \text{III-21}$$

The term a_1 is the backward tilt in flapping and is given by the expression (Eq. 65, Ref. 12)

$$a_1 = t_{1,4}\lambda + t_{1,5}\theta_0 + t_{1,6}\theta_1 = t_{1,4}\lambda + t_{1,5}\theta_{.75}$$

In most forward flight conditions $a_1 < B_{1S}$, where B_{1S} is the forward cyclic, so the first term is negative, pitching nose down. The term K is the hub pitch constant, ft-lbs/deg:

$$K = \frac{eb\Omega^2 M_S}{2}$$

The second term adds to the first if $\dot{\theta}_f$ is negative (pitching nose down), but the whole term is usually small and can be ignored. Thus the hub moment is

$$M_H = \frac{eb\Omega^2 M_S}{2} (a_1 - B_{1S}) \qquad \text{III-22}$$

For the CH-53D:

$$e = 2.0$$
$$b = 6$$
$$M_s = 184$$
$$\Omega = 22$$

Thus

$$M_H = \frac{2 \times 6 \times \overline{22} \times 184}{2} (a_1 - B_{1S}) \qquad \text{III-23}$$
$$= 5.35 \times 10^5 \; (a_1 - B_{1S})$$

The value of $a_1 - B_{1S}$ may be as high as -3° so M_H might be about - 28000 ft-lbs. for the CH-53D.

III-4 Fuselage Forces and Moments

The equations for fuselage lift, drag and pitching moment are based on wind tunnel data for the CH-53D presented in Refs. 10 and 11, and shown graphically in Ref. 5. A polynomial was fitted to the data for the range of fuselage angle of attack from -16° to +16°. The resulting equations are

$$\text{LIFT} \quad L_F/q = 15.0 + 487\ \alpha_F \qquad \text{III-24}$$

$$\text{DRAG} \quad D_F/q = 41.696 - 11.45\ \alpha_F + 8.423\ \alpha_F^2 \qquad \text{III-25}$$

$$\text{FOR THE RANGE} \quad -20° \leq \alpha_F \leq + 20°$$

$$\text{MOMENT} \quad M_F/q = -450 \qquad -20 \leq \alpha_F \leq -12 \qquad \text{III-26}$$

$$M_F/q = 58.8\ \alpha_F \qquad -12 \leq \alpha_F \leq + 16 \qquad \text{III-27}$$

$$M_F/q = 1000 \qquad +16 \leq \alpha_F \leq + 20 \qquad \text{III-28}$$

The lift data is for fuselage and tail. The tail incidence equals 3°. The drag data is for the complete aircraft, including rotor head, antenna, cooling losses, etc. The moment data is for the complete aircraft, minus the tail. The full-scale data shown in Ref. 5 has been transferred to a c.g. at station 386 and a waterline station of 161.4.

III-5 Tail Forces and Moments

The horizontal tail lift coefficient is

$$C_{L_T} = a\ (\alpha_T - \alpha_o) \qquad \text{III-29.1}$$

where the angle of attack α_T is

$$\alpha_T = \theta_f + i_T - \epsilon_T + \epsilon_p \qquad \text{III-29.2}$$

and α_o is the zero lift angle. The slope of the lift curve $a = C_{L_{T_\alpha}}$ is

$$a = \frac{\pi\,AR}{1 + \sqrt{\left(\frac{\pi\,AR}{a_o}\right)^2 + 1}} \qquad \text{III-29.3}$$

where a_o is the lift curve slope for the airfoil section and is taken to equal 5.73. For an aspect ratio equal to 2.5, a = 2.88/RAD or 0.05/DEG.

α_T, the angle of attack of the tail, is equal to the fuselage pitch angle θ_f, the tail plane incidence angle i_T, the downwash interference angle ϵ_T and an additional angle of attack change produced by the fuselage pitching motion and equal to

$$\epsilon_p = \frac{\dot{\theta}_f \ell_{x_T}}{V}$$

where ℓ_{x_T} is the distance of the tail to the c.g. The angle ϵ_T is discussed in the next section.

$$C_{M_T} = \ell_{x_T} C_{L_T} \qquad \text{III-29.4}$$

Tail drag is a part of fuselage drag and included in Equation III-25.

III-6 Interference Angles

The generalized equations of motion contain the downwash interference angles

(1) ϵ_{FUS} Rotor on fuselage III-30

(2) ϵ_T Rotor on tail III-31

which apply in this case, as well as several others (ϵ_F, ϵ_R, ϵ_W, ϵ_{VT}, and ϵ_{TR}) which do not apply. The formulas ϵ_{FUS} and ϵ_T are taken from Ref. 4, section 5.

$$\epsilon_{FUS} = \operatorname{Tan} \alpha_c - \frac{\lambda}{\mu}$$

$$\epsilon_T = \operatorname{Tan} \alpha_c - \frac{\lambda}{\mu}$$

Some consideration was given to the use of the formula

$$\varepsilon_T = K_{FT} \left[\mathrm{Tan}\ \alpha_c - \frac{\lambda}{\mu} \right]$$

where K_{FT} is a function of the rotor wake angle

$$x = a_1 + \mathrm{Tan}^{-1} \left[- \frac{\mu}{\lambda} \right]$$

The functional relationship is shown in Ref. 4, Section 5, Figure 1. For a range of x from 40° to 80°, K_{FR} (and K_{FT}) ranges from 0.37 to 1.46. Since no information was available on the wake angle x for the flight conditions of interest, it was decided to defer this question.

III-7 Automatic Flight Control System (AFCS)

The simulation model of the AFCS is mathematically identical, except in one minor respect, to the AFCS installed in the CH-53D aircraft. The exception is due to the finite difference nature of the AFCS simulation which delays the feedback one time step. The pitch transfer function of the AFCS feedback loop is derived as follows:

$$B_{1s} = K_R\dot{\theta}_f + K_p\theta_f$$

where B_{1s} is the cyclic pitch of the swash plate

θ_f is the pitch angle of the fuselage and K_R and K_p are the rate and proportional gains. The transfer function is

$$\frac{B_{1s}}{\theta_f} = K_p\ (TS + 1)$$

where $T = \left(\frac{K_R}{K_p}\right)$. The feedback gains for optimum performance have been derived in Reference 5, for the aircraft system

$$\frac{B_{1s}}{\theta_f} = .4(S + 2)\ \text{°cyclic/°fuselage}$$

The question of time delay referred to above is of interest. If the AFCS simulation were described by continuous (analytic) differential equations, the time delay could be represented by the transfer function e^{-st} and its effect could be readily determined by the various techniques of control system analysis, say by a Nyquist plot. However, when the AFCS simulation employs difference equations, the control feedback is delayed, i.e.,

$$(B_{1s})_{t=t_n+T} = K_R\,(\dot{\theta}_f)_{t=t_n} + K_p\,(\theta_f)_{t=t_n}$$

and the value of B_{1s} is calculated from the values of $\dot{\theta}_f$ and θ_f at the previous time step.

Figure III-2 shows the effect of step size. The curves trace the motion in the x-z plane. At the end of seven intervals (8.4 seconds) the coordinates are:

h	8.4/h	x	z
.010	840	.20	3.85
.025	336	.70	3.00
.050	168	1.02	3.38
.100*	84	2.30	4.10
.150*	60	4.90	6.90

*curves not shown in Figure III-2.

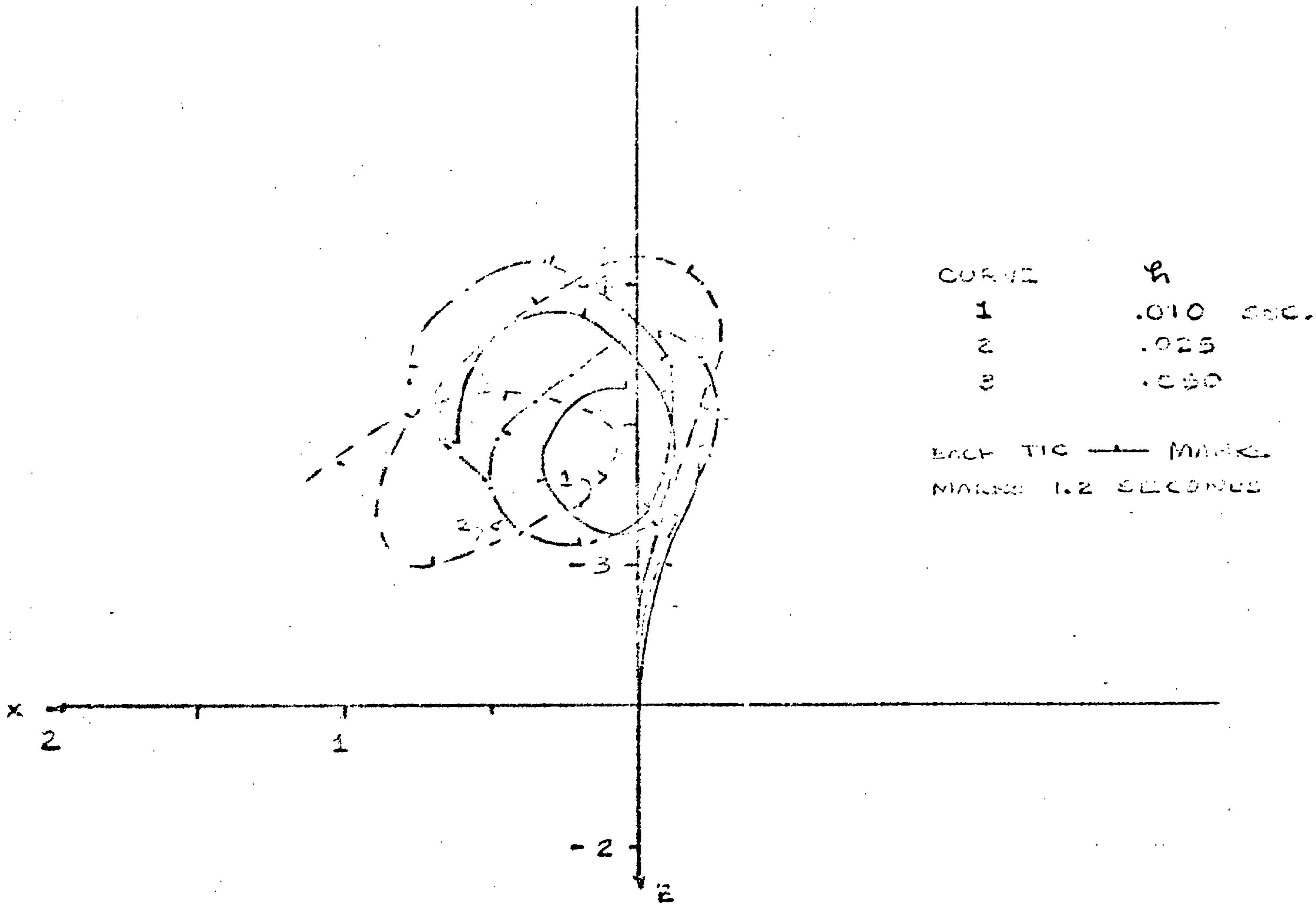

Figure III-2 Effect of Integration Step Size on Hover Behavior - CH-53 Helicopter

It can be seen from the results above and from Figure III-2 that the error due to the finite difference representation of the AFCS is not large if the step size is less than .050, <u>for the hover conditions only</u>. Conservatively assuming that all the differences in Figure III-2 were due to the delayed feedback error, then the error incurred in increasing the step size from .010 to .025 would be .

$$\varepsilon_A = \frac{\sqrt{(.70-.20)^2 + (3.85-3.00)^2}}{336} = \frac{.987}{336}$$

$$= .00294$$

which is less than h but greater than h^2. It can be shown by the examination of a simplified version of the equations of motion that the delayed feedback error is of order Nh, but not Nh^2, where N is a positive number which is a function of the x force.

III-8 The Ground Effect

Figure III-3 shows the variation of the ground effect parameter

$$\Lambda = \frac{\text{rotor thrust in ground effect}}{\text{rotor thrust out of ground effect}}$$

as a function of the ratio Z/R

Z = distance of rotor head above ground

R = rotor radius

in terms of the ratio V/U_o

V = forward speed (-U)

$$U_o = \left(\frac{T}{2\pi \rho R^2 B^2}\right)^{1/2} = \text{induced velocity in hover}$$

V = tip loss factor = 0.97

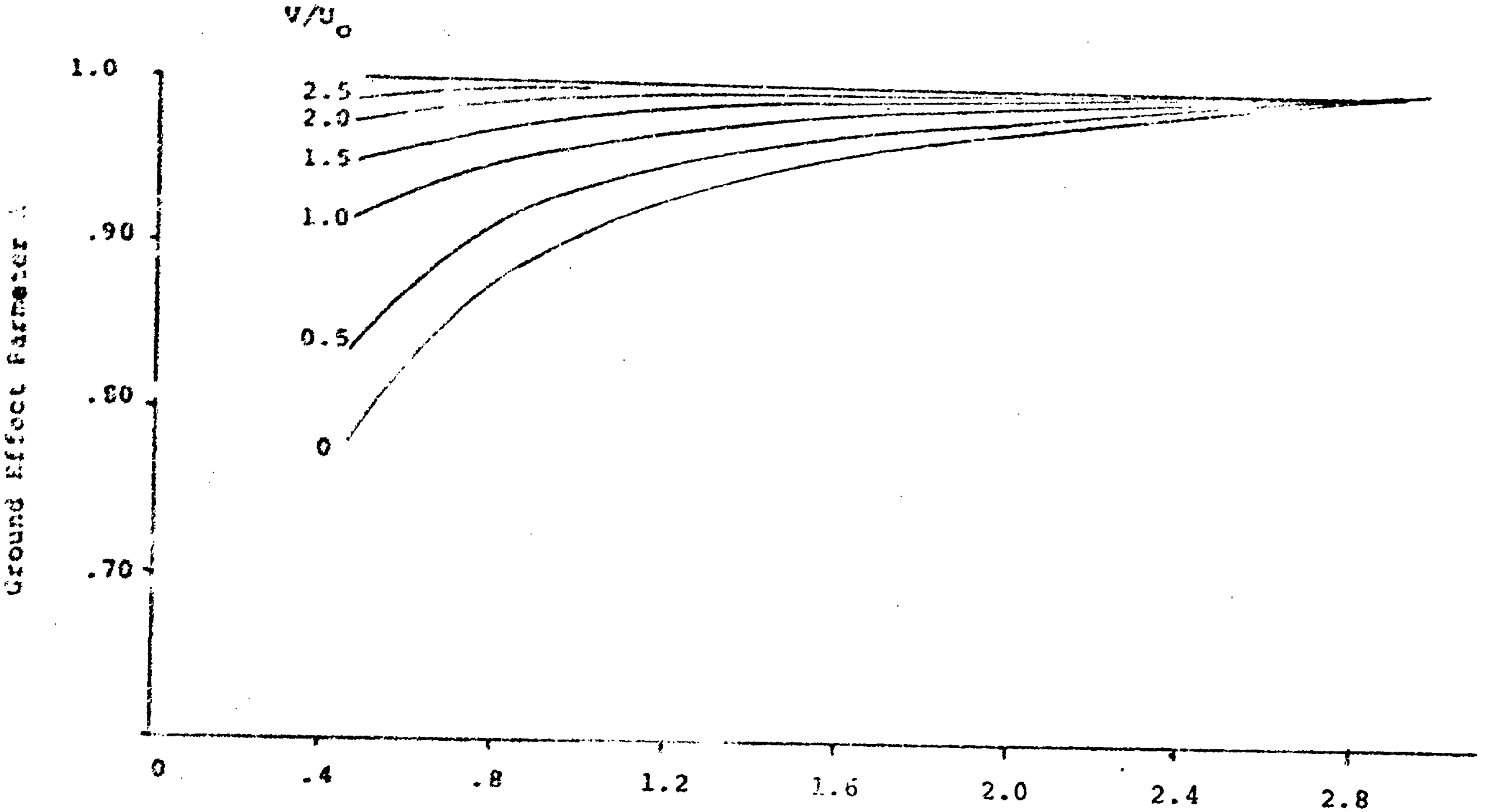

Figure III-3 Ground Effect Parameter Λ vs. Z/R

For T = W = 33500

$$U_o = \left(\frac{33500}{(2\pi)(0.00238)(36)^2(0.97)^2} \right)^{1/2}$$

$$= 76.7 \text{ fps}$$

Since the launch/recovery operations are limited to an initial or terminal speed of about 25 knots ship velocity and 45 knots wind velocity (the maximum allowed for CH-53D wind-up)

$$V = 70 \text{ knots at take-off}$$

$$= 118 \text{ fps.}$$

and $V/U_o = 1.55$.

The parameter Λ gives the reduction in thrust due to ground effect. Ground effect will alter each of the variables computed above, since the effective thrust is reduced. Since the LARC-I calculation begins with a value of thrust (in terms of T_R/W), and this value is multiplied by Λ (as a function of F/U_o), then the values for C_T, C_{Q_R}, θ_o, α_c, H, L_F and D_F all include the ground effect. However, it should be noted that the unbalanced moment due to a rotor being only partially in the ground effect, as when the rotor extends over the edge of the deck, is not included.

IV. GENERAL DESCRIPTION OF THE LARC-I SIMULATION

The LARC-I (LAunch and Recovery Capability) simulation provides the necessary coupling between the motions of the ship, discussed in Section II, and the aircraft motions, discussed in Section III. The motions of the ship are confined to the x-z plane (i.e., to heave, pitch and longitudinal velocity) and those of the aircraft to longitudinal and vertical velocity and to pitching about the aircraft center of gravity.

Physical interaction of the ship and the aircraft occurs only through the landing gear forces and moment:

$$Z_{LG} = - (F_{LG_N} + F_{LG_M})$$

$$X_{LG} = \text{brake force} = \pm \mu_F Z_{LG}$$

$$M_{LG} = F_{LG_N} X_{LG_N} + F_{LG_N} X_{LH_N}$$

(μ_F = coefficient of friction, usually 0.3)

F_{LG_N} and F_{LG_M} are, respectively, functions of S_N and S_M, the extension or stroke of the nose and main landing gear shock strut cylinders which are in turn functions of the relative aircraft and ship positions. The equations for stroke are shown in Appendix C, page C-1. It is only in these equations, in the terms $Z_{i_{LP}}$ (vertical position of the ship two aircraft launch/landing points) and $\dot{Z}_{i_{LP}}$ (velocity of the same points) that the ship motion interacts with the aircraft and the interaction through the landing gear forces persists only as long as the aircraft is in contact with the deck.

The variables $Z_{i_{LP}}$ and $\dot{Z}_{i_{LP}}$ are in turn harmonic functions of time which include the coupled heaving and pitching of the ship in response to waves of a random sea. The sea state is, in this simulation, characterized by a single parameter, the significant wave height $h_{1/3}$ which may take values (crest to trough) of up to 100 feet in sea state 9 conditions.

Further coupling between the ship and the aircraft occurs indirectly through their relative motions. Since both the ship and aircraft motions are referred to a body axis system it is necessary to refer the motion of each vehicle to known fixed inertial axes (see Figure IV-1) in order to obtain the relative motion between the vehicles. The necessary transformation equations are given in Appendix B.

IV-1 Structure of the LARC-I Simulation Program

Figure IV-2 is a simplified block diagram of the LARC-I simulation program. The simulation may be described as a fixed control non-steady state model. Each computer run simulates a segment of length T (seconds) during which the program computes the motion at $N = \frac{T}{\Delta T}$ instants (ΔT is the time step) during which all input variables including the controls remain fixed. If all aircraft initial input coodinate constants $(x_o, \dot{x}_o, z_o, \dot{z}_o, \theta_o, \dot{\theta}_o, t_o)$

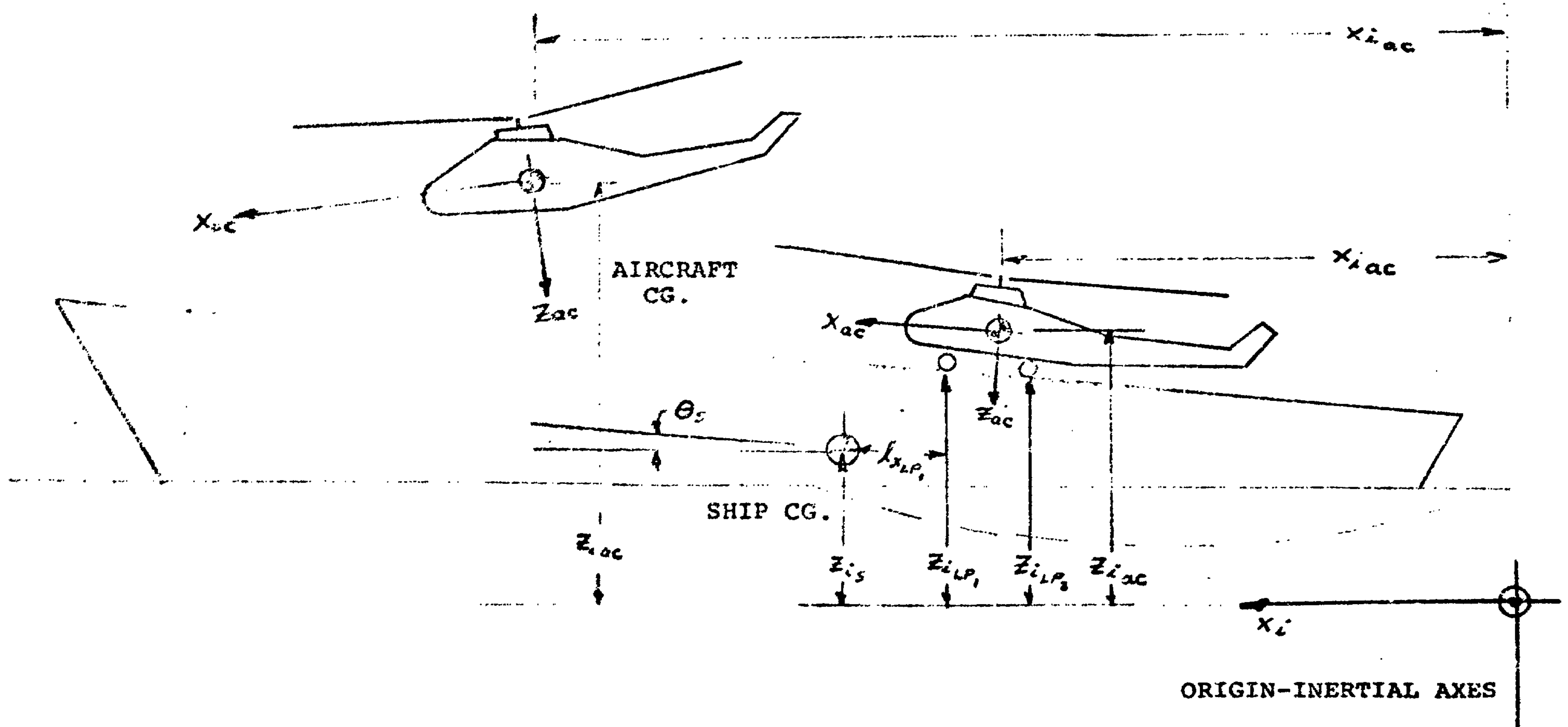

FIGURE IV-1 INERTIAL COORDINATE RELATIONSHIPS

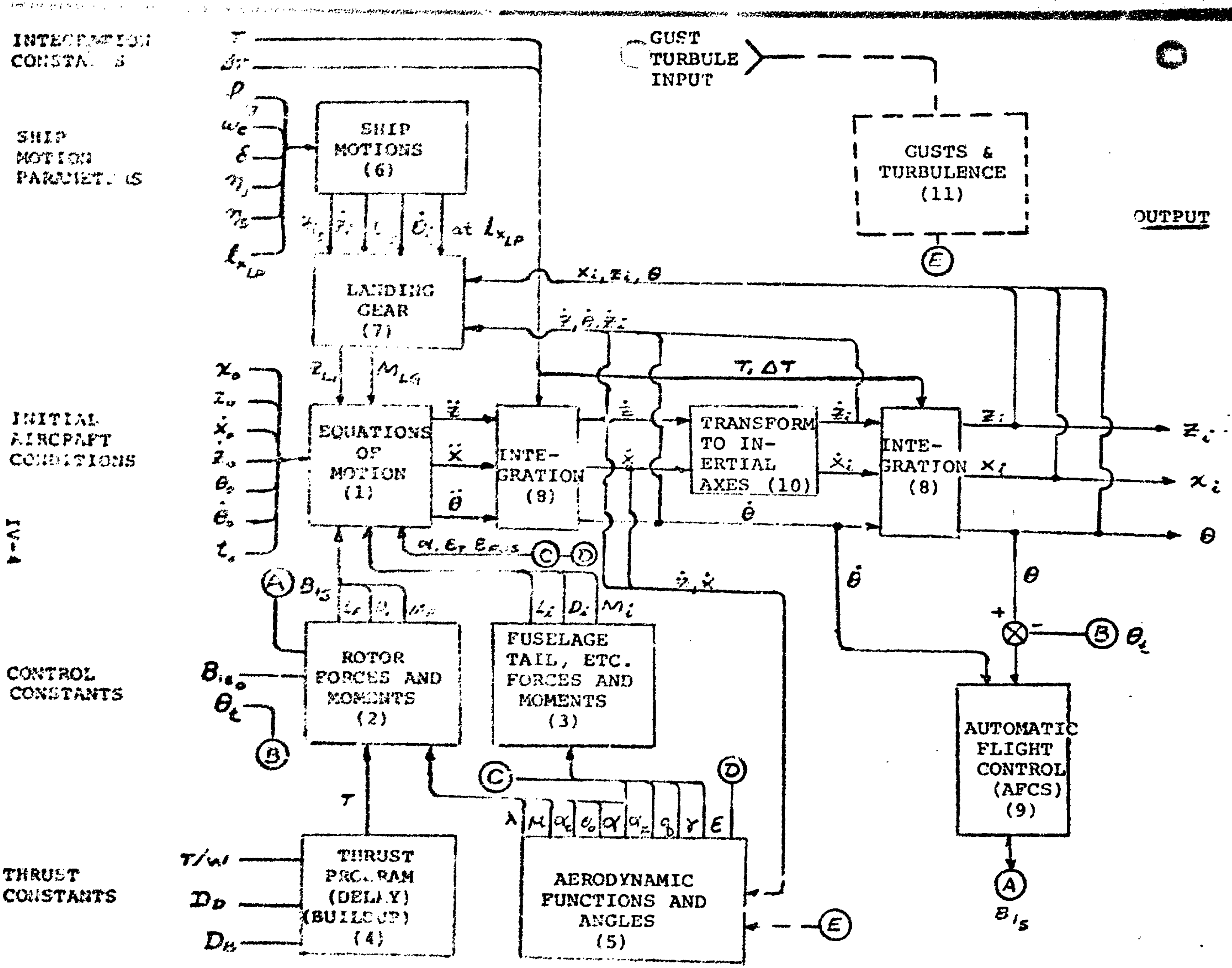

FIGURE IV-2 SIMPLIED AIRCRAFT SIMULATION BLOCK DIAGRAM are set to zero, the aircraft is placed on the deck at a distance $\ell_{x_{LP}}$ from the ship's center of gravity.

The sequence of operations for the simulation which uses a fourth-order Runge Kutta scheme to numerically integrate the equations of motion is shown in Figure IV-2. At each time instant T_i the force and moment modules (2), (3) and (7) compute the forces and moments based on the attitude and velocity of the aircraft at the end of the previous time step, $T_i - \Delta t$, and, if the aircraft is in contact with the deck, the position and velocity of the ship, block (7). At each time T_i, a value of B_{ℓ_S} is calculated at block 9 based on the value of $\dot{\theta}_f$ and $\dot{\theta}_f$ at the previous time $T_i - \Delta T$.

If the thrust/weight parameter (T/W) is greater than one, the aircraft will ascend, if less than one, the aircraft will descend. The thrust may be delayed D_B seconds by assigning a value to the delay parameter D_D. This allows the take-off sequence to start at some specified point in the ship motion cycle. Experience has shown that the parameter D_B is less important in the landing sequence. Also, the thrust may be specified to increase linearly from zero to (T/W)W pounds in D_B seconds for use primarily in the take-off sequence.

The initial longitudinal cyclic $B_{\ell_{S_0}}$ may be specified. However, the Automatic Flight Control System will continuously vary B_{ℓ_S} according to the equation

$$B_{\ell_s} = K_r\dot{\theta}_f + K_p\ (\theta_f - \theta_t)$$

where K_p is the proportional gain, K_R the rate gain, θ_f the fuselage pitch angle, and B_{ℓ_s} is the swash plate tilt angle relative to the rotor shaft. The effect of assigning a value to B_{ℓ_s} may reduce the magnitude of a transcient motion, since otherwise $B_{\ell_{s_o}}$ is assumed zero.

The trim pitch angle is the fuselage pitch corresponding to near equilibrium conditions at a thrust equal to (T/W)W and for all other values of the initial conditions. For a given gross weight and c.g. position, θ_t is a function of forward velocity. If θ_t is not known for a given velocity, it may be found by a trial and error procedure. Since the LARC program outputs all forces as functions of time, the trim angle for a given speed may be easily approximated using the data from a few runs. Although trim pitch is specified, the aircraft in the simulation is rarely, if ever, in a state of trim, or steady state flight, although the changes about the trim value will not be large. The thrust program is shown in block 4. The integration scheme is shown in block 8. The dashed block 11 refers to the model for gusts or turbulence, which, although very simple, was not included in the present version of the simulation.

IV-2 Operation of the LARC-I Program

The following remarks are intended to illustrate the operation of the simulation. They are not intended to serve as a user manual. Operation of the program is quite simple. A user with no prior knowledge of the program itself, or prior background in programming, can make full independent use of the program after only very brief instructions.

The program is designed for interactive operation on a time-shared computer using a remote terminal. The user communicates by means of the terminal keyboard. The program response is by terminal print-out or graphic display. Equipment used in this project was a Honeywell H-1648 time-shared computer, accessed by various remote terminals such as Tektronix 4010 and Typagraph 3 and DP-30.

The LARC-I program written almost entirely in FORTRAN IV, is essentially machine-independent. Certain output, plotting and file processing routines which are required by the particular interactive graphics terminal (Tektronix 4010) are features of the H-1648 time-shared operating system. Since these features are common to most time-shared systems, operation of the program or computer systems other than the H-1648 can be accomplished with relatively small changes in the coding. Machine independency was a major goal of this project.

All processing on the time-shared system is done using files which contain programs or data; each file is created independently. The files are accessed by reference to file name, either internally in the program or by means of an interactive command. Data files may be created in their entirety, may be searched for specific elements, or may be changed by altering specified elements or groups of elements.

Subsequent to the creation of the data files referred to below, and to the compilation of the LARC-1 program, the sequence of interactive commands may appear as follows (the user replies are underlined):

TYPE AIRCRAFT TYPE *** <u>CH53</u>

The user response loads a file entitled "CH53", containing the input data shown in Appendix C. The user may select any data file which he has previously created, each representing a particular aircraft configuration. Elements of this file may not be altered during run time.

** <u>D</u>

The user response loads the parameter file DEFALT. The values of this file may be changed during run-time in the manner described below

** <u>I</u>

The user response "I" for INPUT, signals the intention of changing values in the parameter file DEFALT. If this response is not made, the DEFALT file is loaded as compiled prior to run-time.

PARAMETER CODES - YES OR NO <u>NO</u>

If the user response is "YES", the parameter codes are printed as shown in Table IV-1. These codes assign a number to be used in the reponses listed below.

INPUT CODE AND VALUE <u>21,0.05</u>

The user has assigned a value 0.05 to parameter 21 (the run-time). The user may assign values to any or all of the parameters listed in Table IV-1 in any desired order.

INPUT CODE AND VALUE 25

This response is required to terminate the input sequence following the command "I" and return the program to the command mode.

** T

The user response is "T" for take-off but may be "L" for landing. This initiates the computational sequence which continues uninterrupted for $N = T/\Delta T$ steps. Both T (run-time) and ΔT (time step interval) are parameters and may be altered for each run.

** P

In the present version, the user may command output in tabular form, "P" or graphical form, "G".

HOW MANY CURVES (1 - 3) 3

1. - CURVE # ** 1

2. - CURVE # ** 2

3. - CURVE # ** 10

Here, the user specifies the curves to be printed or displayed graphically in any desired order, in groups of one to three curves. Appendix A contains examples of the printed output. Table IV-2 lists the output parameters which may be printed on command. These 29 files are loaded in their entirety each time the program executes through the computation sequence. The user may limit the output in any desired manner by specifying from 1 to 30 curves in groups of one to three. After the output of each group, the program will print the command signal "**" at which time the user may respond with:

- P or G — continuing the output sequences as described above
- D — initiating another run in which parameter changes may be made as described above.

Other commands which might be made are:

- N — for NEW CASE which re-initiates the input cycle from the beginning. The program response to this is:

  TYPE AIRCRAFT TYPE

  allowing the user to load the file pertaining to another configuration or model of the same aircraft, or a different aircraft.
- L for LANDING which sets certain program switches pertinent to the landing calculation.
- E for END which stops execution.

Regardless of the number of steps $N = T/\Delta T$, the program stores only 50 values. All 50 values are used in graphing the variables shown in Table IV-2, but only 25 values are printed. If the user desires more accurate resolution, he must accomplish this by decreasing the number of steps $N = T/\Delta T$, by shortening the run time T. N must equal at least 50.

Individual runs may be continuations of a prior run. Table IV-3 and Figure IV-3 illustrates the procedure. The values in Table IV-3 for case I are taken from Appendix A, Series II, case 1. The run time for this case was 15 seconds. The analyst chose to change thrust and fuselage trim at t = 9.6 seconds. The initial conditons for case 1.1 are those which prevailed at t = 9.6 in case 1, plus the control changes. This procedure may be repeated any number of times to compute the flight path of a maneuver, during each segment of which the controls are fixed.

TABLE IV-1
PARAMETER CODES

AIRCRAFT INITIAL CONDITIONS	
1. A/C INERTIAL X POSITION	(X)
2. A/C INERTIAL Z POSITION	(Z)
3. A/C PITCH RATE	($\dot{\theta}$)
4. A/C PITCH ATTITUDE	(θ)
5. A/C VELOCITY - X DIRECTION-BODY AXES	(U)
6. A/C VELOCITY - Z DIRECTION-BODY AXES	(W)
AIRCRAFT CONTROLS	
7. THRUST TO WEIGHT RATIO	(T/W)
8. CYCLIC PITCH-LONGITUDINAL	(B_{1s})
9. FUSELAGE PITCH TRIM ANGLE	(θ_T)
SHIP MOTIONS	
10. SHIP HEAVE AMPLITUDE	(η_3)
11. SHIP PITCH AMPLITUDE	(η_5)
12. SHIP ENCOUNTER FREQUENCY	(μ)
13. PHASE ANGLE - PITCH TO HEAVE	(δ)
SHIP INITIAL CONDITIONS	
14. INITIAL SHIP X CG INERTIAL	
15. INITIAL SHIP Z CG INERTIAL	
16. INITIAL LAUNCH/RECOVERY PT - X	
17. INITIAL LAUNCH/RECOVERY PT - Z	

TABLE IV-1 (Cont'd)

	SHIP VELOCITY	(V_s)
	<u>WIND AND SEA STATE CONDITIONS</u>	
18.	WIND VELOCITY	(V_H)
19.	SIGNIFICANT WAVE HEIGHT	$(h_{1/3})$
20.	<u>INTEGRATION CONSTANTS</u>	
21.	RUN TIME	(T)
22.	TIME STEP	(ΔT)
	<u>PARAMETER CODES</u>	
	<u>THRUST TIME CONSTANTS</u>	
23.	THRUST DELAY TIME	(D_D)
24.	THRUST BUILD-UP TIME	(D_B)
	PROGRAM CODES	
25.	TIME AT INITIAL STEP	(T_o)
26.	CONTINUE	

TABLE IV-2

OUTPUT PARAMETER LIST

CURVE NUMBER	CURVE LABEL	PARAMETER	
1	U A/C	A/C FLIGHT VELOCITY	BODY AXES
2	W A/C	A/C VERTICAL VELOCITY	BODY AXES
3	THETA DOT	A/C PITCH RATE	BODY AXES
4	THETA	A/C PITCH ATTITUDE	BODY AXES
5	X(I) A/C	A/C X POSITION	INERTIAL AXES
6	Z(I) A/C	A/C Z POSITION	INERTIAL AXES
7	XISCG	SHIP CG X POSITION	INERTIAL AXES
8	ZISCG	SHIP CG Z POSITION	INERTIAL AXES
9	FWD CP	NOSE WHEEL DECK CONTACT POINT	INERTIAL AXES
10	AFT CP	MAIN WHEEL DECK CONTACT POINT	INERTIAL AXES
11	FLGN	A/C NOSE GEAR LOAD	LBS
12	FLGM	A/C MAIN GEAR LOAD	LBS
13	B1F	CYCLIC PITCH-LONGITUDINAL	RAD
14	ALPHA	ROTOR ANGLE OF ATTACK	RAD
15	GAMMA	CLIMB (OR DESCENT) ANGLE	RAD
16	THRUST	THRUST	LBS
17	ZF	ROTOR Z FORCE (BODY AXES)	LBS
18	XF	ROTOR X FORCE (BODY AXES)	LBS
19	ZLG	LANDING GEAR FORCE	LBS
20	XLG	LANDING GEAR BRAKE FORCES	LBS
21	MLG	LANDING PITCHING MOMENT	FT-LBS

TABLE IV-2 (Cont'd)

CURVE NUMBER	CURVE LABEL	PARAMETER	
22	MGL	MAIN GEAR STROKE	INCHES
23	NGL	NOSE GEAR STROKE	INCHES
24	LF	LIFT ROTOR	LBS
25	DF	DRAG-ROTOR	LBS
26	LFUS	LIFT-FUSELAGE	LBS
27	DFUS	DRAG-FUSELAGE	LBS
28	LT	LIFT-TAIL	LBS
29	DT	DRAG-TAIL	LBS

TABLE IV-3

FLIGHT PATH DATA - CH5 - SERIES II Cases 1 and 1.1

Initial Conditions $t=0$ $x=z=\dot{x}=\dot{z}=\theta=\dot{\theta}=0$ $T=33600$ $\theta_t=.014$

t	x	z	U ($\dot{x}$)	W ($\dot{z}$)	θ	$\dot{\theta}$
0	0.0	-33.50	0.0	0.00	0.00	0.00
.6	-0.05	-34.45	-.43	-1.82	.00	0.00
1.2	-0.52	-35.55	-.62	-1.86	.01	0.013
.	.	.	.	.	.	.
9.0	5.68	-40.50	4.84	.81	-.019	-0.139
9.6	7.71	-39.91	2.06	.96	-.049	0.043
10.2	8.30	-39.24	1.21	1.18	.017	0.100
.	.	.	.	.	.	.
14.4	29.62	-35.21	6.43	-2.57	-.018	0.050
14.7	31.36	-35.94	5.51	-2.38	-.008	0.102

Initial Conditions @ T = 9.6
x = 7.71 U = 2.06 θ = -0.49 T = 33650
z = -39.91 W = .96 $\dot{\theta}$ 0.043 θ_t = .044

t	x	z	U ($\dot{x}$)	W ($\dot{z}$)	θ	$\dot{\theta}$
9.6	7.71	-39.91	2.06	.96	-.049	0.043
10.2	11.61	-40.50	4.38	-1.90	-.055	-0.030
10.8	16.40	-42.16	6.95	-3.23	-.183	-0.045
.	.	.	.	.	.	.
16.2	25.30	-53.40	3.05	-3.87	-.238	-0.003
16.8	27.20	-55.37	3.43	-3.93	-.242	-0.008
17.4	28.96	-58.20	3.92	-4.16	-.256	+0.009
.	.	.	.	.	.	.
24.0	66.38	-77.30	8.93	-4.06	-.176	+0.072
24.4	70.24	-79.16	11.26	-3.92	-.154	+0.083

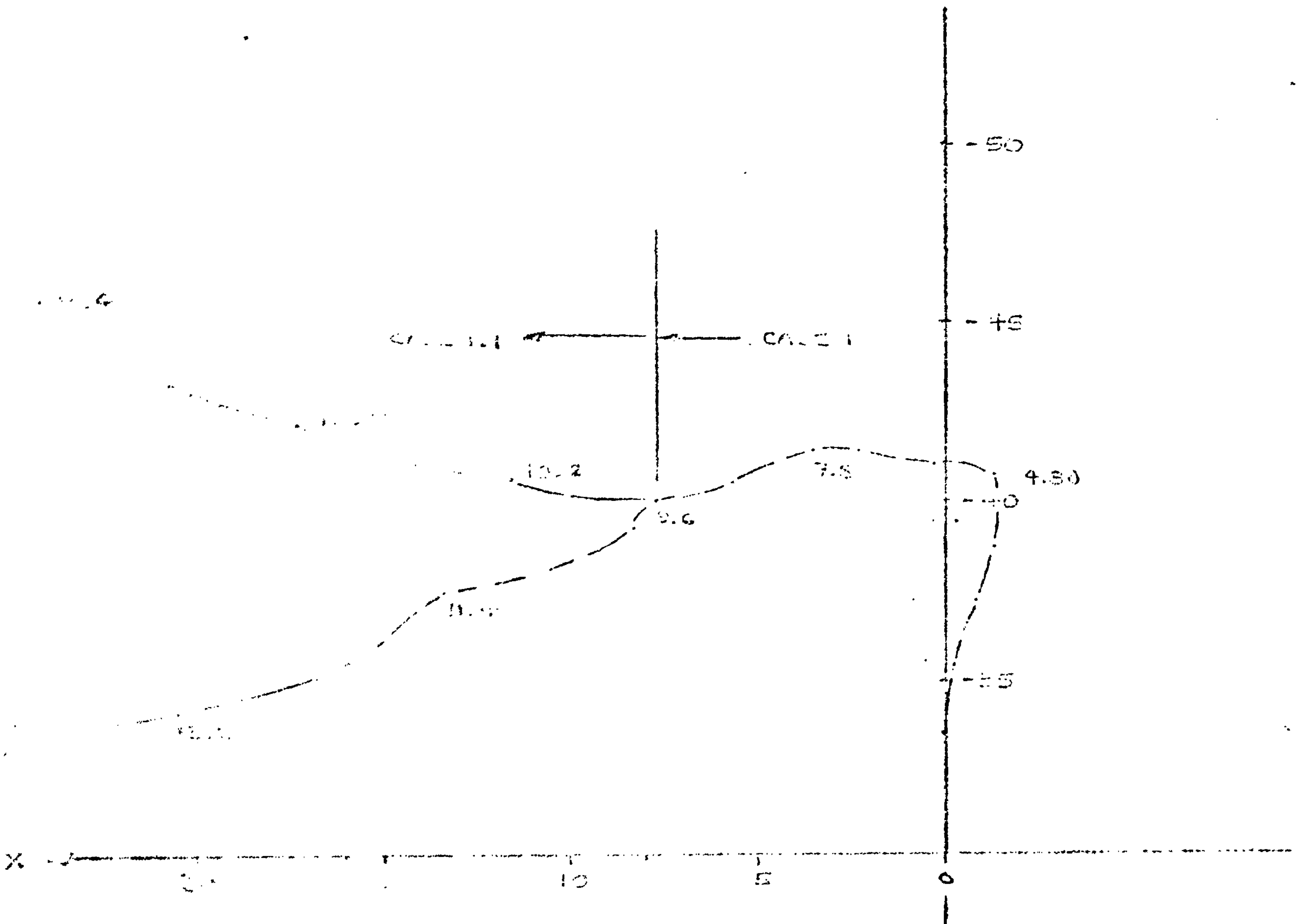

Figure IV-3 FLIGHT PATH CH53
SERIES II CASES 1 and 1.1

V. RESULTS

Over 350 computer runs were made, 34 of which are shown in the tabulations of Appendix A. The principal object of these runs was to test the program and to gain experience in its use. Thus, these runs do not necessarily represent a systematic evaluation of the aircraft/ship compatability problem. Budget constraints prevented an in-depth parametric survey of all aspects of this problem. In fact, the "ship" itself is only an approximation, since no detailed and accurate information was available to model a specific ship design. However, important conclusions have been drawn about the effects of ship motions on aircraft control and stability:

(1) Even for the most severe ship motions (a wave height of 30 ft., an encounter frequency of 0.3 rad/sec., Series III, Case 11) the CH-53D control margin is adequate for normal take-off. For ship encounter frequencies from 0.3 to 0.68 rad/sec., corresponding roughly to periods of 2.05 to 9.0 seconds, the ship motions are quite slow in comparison to the aircraft motions. Series III, case 4, represents a severe ship motion. In this case, the ship is heaving in a 30-ft. wave with an amplitude of 18.3 feet, and a period of 9 seconds. The ship is at zero amplitude at t = o. The maximum aircraft rotor thrust is attained at t = 5 seconds and the aircraft is off the deck by t = 5.0 seconds. Despite the large ship excursions, there is no

excessive build-up in landing gear forces. The aircraft pitches forward about 3.5 degrees during the first three seconds, lifting the main gear off the deck. The nose gear force remains low, however, and vanishes at about t = 5.0 seconds. At no time during this 5-second period does the pitching acceleration of the aircraft exceed $\pm$ 0.105 rad/sec.

(2) In all the runs tabulated in Appendix III, take-off occurred from a rising deck, at a time when the deck upward velocity was near a maximum. Other runs, monitored visually, were made for take-off from descending decks, also at maximum velocity. In no case were large or destabilizing moments transmitted to the aircraft. Case 1 of Series III is typical. Here, the deck is ascending at a rate of $1/2\ h_{1/3}\mu^2 = (15)(.68)^2 = 7.0$ ft/sec at t = 0. It is assumed that the aircraft is released at t = 0 at a distance of 7.5 inches above the static gear extension. Even so, the maximum total gear load is only 46500 pounds at t = 0.6 sec. (A/C gross weight is 33500 lbs.), and the landing gear pitching moment is -104000 in.-lbs. nose down. The pitching velocity (THETA DOT) remains very low.

(3) Since the ship pitch amplitude was small (5.492° or less) all runs were made with take-off from a point above the ship center of gravity. In the worst case, the ship's pitching motion, leading the heave by as little as $\frac{\pi}{2}$ radians, would add less than 1.3 feet to the total vertical excursion at either bow or stern.

(4) The gains for the AFCS pitch channel were determined for the CH-53D and agree with the optimum values calculated by Sikorsky (Ref. 5). These values are:

$K_R = .4$ rate given

$K_P = .8$ proportional gain

(5) In its present form, the program can be used to determine gains, stability margins or trim conditions, but the procedures are not "optimum". Experience has pointed out changes which can be made to effect rapid convergenge to optimum values by use of adaptive methods. Once optimum gains and trim conditions are identified, stability margins can be readily identified by an analysis of the motion.

(6) Although roll and yaw are suppressed in this model, the simulation yields considerable data which provides insight into the roll behavior. The significant variations in λ (the inflow ratio) and B_{ℓ_s} (the longitudinal cyclic) at frequencies in the neighborhood of 2 to 3 rad/sec., because of the effect on side force, could induce critical coupling for ship motions in the same frequency range. The coupling effects stem from the presence of λ in the side force equation and in the third harmonic flapping term b_1.

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APPENDIX A

SELECTED RESULTS OF COMPUTER RUNS

PRINT-OUT LABELS AND UNITS

TIME	ELAPSED TIME	SECS.
U A/C	VELOCITY IN X DIRECTION	FT/SEC
W A/C	VELOCITY IN Z DIRECTION	FT/SEC
THETA DOT	PITCHING VELOCITY	RAD/SEC
THETA	PITCH ATTITUDE	RAD.
X(I) A/C	X POSITION, A/C C.G.	FT
Z(I) A/C	Z POSITION, A/C C.G.	FT
Z(I) S CG.	Z POSITION, SHIP C.G.	FT
Z FWD CP	Z POSITION FORWARD LANDING GEAR CONTACT POINT	FT
Z AFT CP	Z POSITION AFT LANDING GEAR CONTACT POINT	FT
NOSE GEAR	NOSE GEAR LOAD	LBS
MAIN GEAR	MAIN GEAR LOAD	LBS
ZLG	TOTAL LANDING GEAR LOAD	LBS
MGL	MAIN GEAR STRUT EXTENSION	INCHES
NGL	NOSE GEAR STRUT EXTENSION (FULLY COMPRESSED=0 INCHES, FULLY EXTENDED=12 INCHES)	INCHES
ZF	ROTOR FORCE - Z DIRECTION	LBS
XF	ROTOR FORCE - X DIRECTION	LBS
B1S	CYCLIC PITCH	RAD
GAMMA	FLIGHT PATH ANGLE	RAD

(NOTE: 38 functional values fo each variable are stored of which only 25 values are printed in the following tables. See Page 17-19. Hence the extrema, (first two values in each column of the print-out tables) may or may not be included in the print-out time histories.)

SERIES I ZERO THRUST

CASE	SWH	T	ΔT	
1	0	15	.05	CD = 200
2	0	20	.05	CD = 100
3	10'	20	.05	
4	20'	20	.05	
5	30'	20	.05	
6	5'	60	.10	
7	10'	60	.10	
8	20'	60	.10	
9	50'	60	.10	
10	30	15	.05	DROP HEIGHT = 16"
11	30	15	.05	TAKE-OFF AREA 106' AFT OF MIDSHIPS

FOR ALL CASES (EXCEPT AS NOTED)

DROP HEIGHT = 7.5" (EXCEPT 10)

ENCOUNTER FREQUENCY = .48

TAKE-OFF AREA: MIDSHIPS (EXCEPT CASE 11)

T = Length of run seconds

ΔT = Time step, seconds

SWH = Significant wave height ($h_{1/3}$), ft.(double amplitude)

	TIME	W A/C	THETA DOT	THETA	GEAR LOAD	MGL	NGL
MINIMUM	0.000	-1.253	-0.278	-0.211	-42100.300	1.810	2.791
MAXIMUM	14.999	1.023	0.272	0.212	-16575.105	7.562	7.502
	0.000	0.000	0.000	0.000	-16575.105	7.562	7.592
	0.600	-1.253	-0.278	0.210	-41195.893	1.352	3.426
	1.200	1.234	0.272	-0.002	-33478.679	3.435	3.176
	1.800	-0.071	-0.030	-0.006	-27000.701	3.375	3.204
	2.400	0.025	0.020	0.009	-41079.211	2.023	3.413
	3.000	0.490	0.026	-0.005	-32741.277	3.593	2.643
	3.600	-0.507	-0.041	0.002	-32216.083	2.988	3.356
	4.200	0.540	0.035	0.004	-35900.710	2.642	3.105
	4.800	-0.133	-0.014	-0.004	-32019.500	3.558	2.906
	5.400	-0.205	-0.012	0.007	-37843.828	2.331	3.436
	6.000	0.433	0.029	-0.003	-31654.047	3.348	2.357
	6.600	-0.623	-0.038	0.001	-31702.006	3.116	3.232
	7.200	0.475	0.020	0.005	-30786.531	2.512	3.265
	7.800	-0.252	-0.035	-0.005	-20933.797	3.020	2.920
	8.400	-0.302	-0.020	0.000	-30050.734	2.410	3.421
	9.000	0.571	0.034	-0.001	-32528.436	3.233	3.225
	9.600	-0.554	-0.035	-0.001	-30007.075	3.200	3.165
	10.200	0.340	0.022	0.006	-37596.211	2.394	3.319
	10.800	0.105	0.004	-0.005	-32225.730	3.610	2.329
	11.400	-0.524	-0.029	0.005	-35444.477	2.564	3.386
	12.000	0.601	0.037	0.000	-33546.937	3.221	3.205
	12.590	-0.449	-0.029	-0.002	-33544.050	3.410	3.204
	13.199	0.185	0.013	0.007	-33372.402	2.325	3.361
	13.799	0.242	0.013	-0.004	-32304.916	3.565	2.026
	14.399	-0.629	-0.035	0.004	-34082.312	2.732	3.319
	14.999	-0.352	-0.026	-0.004	-29022.065	3.032	2.936

SERIES I CASE 1 ZERO THRUST ZERO WAVE HIGH DAMPING

	TIME	W A/C	THETA DOT	THETA	U A/C	X(1) A/C	Z(1) A/C
MINIMUM	0.000	-0.500	-0.023	0.000	0.000	0.000	-33.000
MAXIMUM	19.600	0.221	0.125	0.057	0.000	0.023	-32.612
	0.000	0.000	0.000	0.000	0.000	0.000	-33.000
	0.800	-0.500	-0.022	0.048	0.000	0.015	-32.744
	1.600	-0.413	-0.022	0.050	0.000	0.018	-32.724
	2.400	-0.200	-0.020	0.052	0.000	0.017	-32.713
	3.200	-0.172	-0.009	0.052	0.000	0.017	-32.722
	4.000	-0.070	-0.003	0.052	0.000	0.017	-32.722
	4.800	0.073	-0.000	0.051	0.000	0.017	-32.727
	5.600	0.079	0.003	0.051	0.000	0.017	-32.725
	6.400	0.166	0.006	0.052	0.000	0.017	-32.720
	7.200	0.239	0.011	0.052	0.000	0.017	-32.713
	8.000	0.312	0.014	0.052	0.000	0.017	-32.711
	8.800	0.372	0.017	0.052	0.000	0.013	-32.702
	9.600	0.410	0.019	0.053	0.000	0.010	-32.692
	10.400	0.452	0.021	0.053	0.000	0.019	-32.681
	11.200	0.466	0.021	0.054	0.000	0.019	-32.670
	12.000	0.461	0.021	0.054	0.000	0.020	-32.658
	12.800	0.436	0.020	0.055	0.000	0.021	-32.647
	13.600	0.300	0.018	0.055	0.000	0.021	-32.636
	14.400	0.325	0.015	0.056	0.000	0.022	-32.625
	15.200	0.240	0.011	0.056	0.000	0.022	-32.619
	16.000	0.144	0.007	0.056	0.000	0.022	-32.614
	16.800	0.034	0.002	0.057	0.000	0.022	-32.611
	17.600	-0.083	-0.004	0.057	0.000	0.022	-32.611
	18.400	-0.223	-0.009	0.050	0.000	0.022	-32.615
	19.200	-0.322	-0.015	0.056	0.000	0.022	-32.623
	19.600	0.279	0.012	0.052	0.000	0.017	-32.714

SERIES I CASE 2 ZERO THRUST ZERO WAVE LO DAMPING

	TIME	NOSE GEAR	MAIN GEAR	MLG
MINIMUM	0.000	4429.342	5972.936	-59207.969
MAXIMUM	10.000	12007.712	37560.268	150534.294
	0.000	12367.742	5572.036	150534.294
	0.500	8773.264	19223.632	39302.150
	1.000	3031.243	21230.510	22240.291
	1.400	3710.018	21010.342	21174.656
	2.000	3717.074	21528.522	22273.123
	3.000	3727.771	21509.758	21220.125
	4.000	3721.182	21472.625	22471.562
	5.000	3714.534	21565.566	21627.430
	6.400	3721.756	21742.547	20407.875
	7.000	3720.727	22262.306	18300.531
	8.000	3731.077	22525.432	15157.460
	9.000	3741.036	23233.608	11430.344
	9.600	3745.054	23740.139	6033.344
	10.100	3756.030	24486.393	1790.375
	11.200	3764.827	25263.137	-3620.375
	12.200	3772.305	26276.363	-9223.375
	13.000	3776.091	26972.210	-14719.125
	13.600	3731.215	27620.346	-19972.252
	14.400	3734.084	28298.453	-24661.075
	15.200	3706.303	28832.026	-28555.107
	16.200	3760.[illegible]	29244.586	-31268.758
	16.200	3780.673	29449.025	-32720.012
	17.000	3765.204	29373.953	-32205.752
	18.400	3770.326	28607.096	-27595.312
	19.000	3781.332	27776.573	-21434.252
	19.000	3731.045	22207.723	16771.000

SERIES I CASE 2 ZERO THRUST ZERO WAVE
LO DAMPING (Cont'd)

H A/C	THETA DOT	THETA
-1.690	-0.270	-0.020
1.104	0.272	0.031
-0.000	0.002	0.005
-1.000	-0.271	[illegible]
-1.034	-0.244	[illegible]
-0.108	0.044	[illegible]
-0.057	0.022	
		0.010
-0.004	-0.219	0.007
-0.007	-0.236	0.020
-0.010	-0.202	0.031
0.305	0.034	0.010
0.334	0.024	0.010
-0.139	-0.015	0.017
-0.554	-0.000	0.021
-0.121	-0.010	0.024
0.085	0.026	0.010
0.700	0.027	0.012
0.312	-0.000	0.024
-0.153	-0.030	0.025
0.225	-0.027	0.026
0.045	0.013	0.025
1.112	0.031	-0.025
0.079	0.022	-0.012
0.295	-0.033	-0.012
-0.220	-0.030	-0.020
0.665	0.027	-0.020
0.147	-0.026	-0.022

SERIES I CASE 3 ZERO THRUST 5' WAVE

	TIME	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C	Z(I) S CG
MINIMUM	0.000	-1.839	-0.070	-0.030	-0.065	-36.329	-3.352
MAXIMUM	19.600	1.164	0.070	0.031	0.005	-32.243	1.118
	0.000	-0.505	0.002	0.000	0.000	-33.500	0.000
	0.800	-1.839	-0.070	0.000	-0.002	-33.531	-0.474
	1.600	-1.534	-0.054	0.004	-0.004	-33.775	-0.939
	2.400	-0.312	0.019	0.027	-0.011	-34.174	-1.335
	3.200	0.192	0.044	0.022	-0.021	-34.682	-1.603
	4.000	-0.207	0.022	0.019	-0.032	-35.143	-2.100
	4.800	-0.064	-0.010	0.020	-0.042	-35.469	-2.520
	5.600	-0.007	-0.036	0.020	-0.045	-35.654	-2.820
	6.400	-0.319	-0.022	0.031	-0.048	-35.876	-3.040
	7.200	0.395	0.034	0.026	-0.054	-36.036	-3.228
	8.000	0.334	0.024	0.019	-0.060	-36.254	-3.313
	8.800	-0.199	-0.015	0.017	-0.061	-36.329	-3.352
	9.600	-0.554	-0.039	0.021	-0.063	-36.234	-3.323
	10.400	-0.121	-0.016	0.024	-0.056	-36.063	-3.223
	11.200	0.685	0.026	0.019	-0.055	-35.957	-3.001
	12.000	0.798	0.027	0.012	-0.054	-35.868	-2.837
	12.800	0.312	-0.008	0.004	-0.051	-35.606	-2.556
	13.600	-0.159	-0.030	0.005	-0.048	-35.324	-2.223
	14.400	0.025	-0.027	0.000	-0.046	-34.904	-1.846
	15.200	0.045	0.013	0.005	-0.046	-34.471	-1.431
	16.000	1.112	0.031	-0.005	-0.047	-34.162	-0.930
	16.800	0.679	0.022	-0.012	-0.048	-33.826	-0.525
	17.600	0.295	-0.033	-0.012	-0.051	-33.329	-0.051
	18.400	-0.026	-0.036	-0.030	-0.053	-32.775	0.424
	19.200	0.685	0.007	-0.020	-0.065	-32.291	0.801
	19.600	0.147	-0.020	-0.02[illegible]	-0.065	-32.243	1.118

SERIES I CASE 3 ZERO THRUST 5' WAVE (Cont'd)

	TIME	XLG	XGL	NGL	NOSE GEAR	MAIN GEAR	MLG
MINIMUM	0.000	0.000	2.067	2.000	5403.071	10030.321	-50322.281
MAXIMUM	20.000	0.000	3.400	7.500	9705.818	32222.041	57323.752

0.000	0.000	8.430	7.563	5403.071	13030.221	38022.375
0.800	0.000	3.506	2.931	9100.577	17612.113	57023.752
1.600	0.000	2.249	3.305	8401.346	27046.024	-27342.710
2.400	0.000	2.067	3.370	8430.314	32222.041	-50322.201
3.200	0.000	2.791	3.076	8713.404	26422.730	-12023.312
4.000	0.000	3.472	2.097	9373.000	21007.035	30037.752
4.800	0.000	3.510	3.032	9073.048	21375.937	28613.044
5.600	0.000	2.074	3.322	8620.299	24407.215	-854.044
6.400	0.000	2.312	3.420	8401.805	29003.892	-40740.520
7.200	0.000	2.000	3.[illegible]	8597.133	20060.600	-19001.275
8.000	0.000	3.404	2.963	8071.400	22220.200	21442.697
8.800	0.000	3.025	2.997	8092.473	28063.926	31084.044
9.600	0.000	3.205	3.279	8780.025	23300.148	9211.050
10.400	0.000	2.373	3.431	8412.314	28928.135	-35055.375
11.200	0.000	2.552	3.293	8544.424	27698.301	-28032.150
12.000	0.000	3.275	2.999	8899.030	23135.113	14196.156
12.800	0.000	3.632	2.953	9022.816	27006.965	32713.219
13.600	0.000	3.233	3.200	9082.853	22423.863	17250.312
14.400	0.000	2.473	3.411	8471.141	27647.202	-27735.812
15.200	0.000	2.415	3.326	8517.033	28037.602	-34193.504
16.000	0.000	3.030	3.246	9812.502	24277.270	4360.037
16.800	0.000	3.612	2.913	9037.063	21234.022	32446.058
17.600	0.000	3.406	3.101	8911.865	21666.539	24839.187
18.400	0.000	2.051	3.361	8549.932	26148.897	-14135.531
19.200	0.000	2.339	3.361	8531.833	29337.500	-43221.204
20.000	0.000	3.486	3.748	8094.750	21362.500	28049.625

SERIES I CASE 3 ZERO THRUST 5' WAVE (Cont'd)

	TIME	W A/C	THETA DOT	THETA	Z(I) A/C	Z(I) S CG	CENT LOAD
MINIMUM	0.000	-2.031	-0.074	-0.035	-39.442	-6.702	-38835.578
MAXIMUM	19.000	1.620	0.060	0.054	-31.271	2.235	-14642.000
	0.000	-1.192	0.024	0.010	-33.500	0.000	-14642.000
	0.760	-2.031	-0.074	0.026	-33.847	-0.049	-27716.237
	1.520	-1.962	-0.038	0.041	-34.520	-1.370	-35114.431
	2.280	-0.700	0.009	0.045	-35.373	-2.771	-38835.578
	3.040	-0.329	0.043	0.042	-36.205	-3.607	-34403.602
	3.800	-0.037	0.015	0.043	-37.008	-4.370	-30727.016
	4.560	-1.131	-0.020	0.044	-37.732	-5.045	-30635.094
	5.320	-1.1[illegible]	0.031	0.051	-38.191	-5.510	-34024.105
	6.080	-0.372	0.090	0.054	-38.600	-6.079	-37020.050
	6.840	0.239	0.035	0.048	-39.028	-6.417	-34244.291
	7.600	0.034	0.013	0.041	-39.346	-6.625	-33493.305
	8.360	-0.376	-0.020	0.030	-39.442	-6.702	-30131.145
	9.120	-0.434	-0.040	0.042	-39.314	-6.630	-33412.205
	9.880	0.203	-0.002	0.041	-39.102	-6.445	-37757.914
	10.640	0.031	0.023	0.032	-38.898	-6.121	-34745.122
	11.400	0.012	0.013	0.022	-38.607	-5.673	-30706.835
	12.160	0.425	-0.026	0.014	-38.115	-5.112	-30222.791
	12.920	0.193	-0.045	0.014	-37.422	-4.447	-32722.697
	13.680	0.703	-0.013	0.012	-36.655	-3.692	-37360.273
	14.440	1.051	0.025	0.000	-35.943	-2.663	-35725.336
	15.200	1.526	0.010	-0.011	-35.230	-1.976	-31435.035
	15.960	0.957	-0.010	-0.010	-34.400	-1.049	-20324.266
	16.720	0.521	-0.045	-0.020	-33.448	-0.121	-31750.044
	17.480	0.775	-0.024	-0.025	-32.458	0.348	-37210.312
	18.240	1.516	0.021	-0.027	-31.596	1.731	-37124.320
	19.000	0.480	-0.041	-0.035	-31.271	2.235	-31242.316

SERIES I CASE 4 ZERO THRUST 10' WAVE

	TIME	NOSE GEAR	MAIN GEAR	MLG	NCL	NGL
MINIMUM	0.222	5433.271	9150.[illegible]	-53343.791	2.[illegible]	2.022
MAXIMUM	19.622	[illegible]56.192	[illegible]27.419	40232.552	[illegible].312	7.562
	2.222	5459.071	9100.622	44847.179	0.319	7.560
	2.312	3327.190	16880.391	40232.502	3.177	2.395
	1.212	8011.275	32012.590	-40009.025	2.[illegible]	3.372
	2.122	3192.121	31457.412	-53343.791	2.147	3.377
	3.222	3727.552	25010.100	-5023.781	2.959	2.131
	[illegible]	[illegible]	21051.500	17425.231	3.437	2.322
	4.322	3302.102	21730.523	22020.201	[illegible]	3.195
	5.022	6029.370	23704.310	-12727.501	2.790	3.397
	6.402	9435.777	22030.075	-32247.312	2.347	3.423
	7.222	8049.512	25038.772	[illegible].750	2.992	3.174
	[illegible]	5008.414	21190.957	27448.425	3.524	2.305
	8.022	5207.[illegible]	21203.542	27264.502	3.510	3.209
	9.022	8542.721	24967.295	-5130.105	2.827	3.335
	10.422	3122.771	20335.115	-30227.[illegible]	2.215	3.442
	11.222	2012.[illegible]	20131.734	-12026.501	2.597	2.272
	12.[illegible]	2231.330	21795.550	20784.337	3.[illegible]	2.355
	12.[illegible]	5010.111	21070.[illegible]	20039.420	3.529	3.410
	13.022	3020.225	24093.090	1315.025	2.033	2.329
	14.422	9145.320	20411.340	-30335.201	2.333	3.427
	15.222	8591.[illegible]	27134.706	-22232.312	2.603	3.232
	16.222	8008.[illegible]	22457.222	22204.107	3.381	2.392
	16.322	9022.250	20034.200	32404.752	3.622	2.366
	17.522	8761.035	22938.149	12427.000	3.116	3.228
	18.422	5483.252	23735.203	-33775.252	2.397	3.209
	19.222	2503.337	28550.781	-32032.531	2.465	3.274
	19.622	9541.740	22420.574	10238.719	3.233	3.105

SERIES I CASE 4 ZERO THRUST 10' WAVE (Cont'd)

	TIME	W A/C	THETA DOT	THETA	Z(I) A/C	Z(I) S CG
MINIMUM	0.000	-5.178	-0.073	-0.111	-49.878	-18.299
MAXIMUM	19.000	3.395	0.130	0.166	-29.264	6.135
	0.000	-3.251	0.012	0.035	-33.580	2.328
	0.800	-5.178	-0.073	0.085	-34.915	-2.592
	1.600	-4.676	-0.053	0.110	-37.013	-5.102
	2.400	-3.349	0.006	0.133	-39.216	-7.569
	3.200	-2.594	0.003	0.142	-41.397	-9.951
	4.000	-2.500	0.012	0.140	-43.435	-11.036
	4.800	-2.054	-0.020	0.157	-45.133	-13.701
	5.600	-2.252	-0.020	0.165	-46.555	-15.347
	6.400	-1.103	0.014	0.166	-47.795	-16.024
	7.200	-0.431	0.026	0.162	-48.779	-17.526
	8.000	-0.374	0.014	0.152	-49.445	-18.295
	8.800	0.258	0.002	0.144	-49.744	-18.209
	9.600	0.632	0.004	0.133	-49.701	-18.135
	10.400	1.515	0.014	0.113	-49.356	-17.024
	11.200	1.998	0.014	[illegible]	-48.711	-16.710
	12.000	2.265	0.004	0.079	-47.733	-15.496
	12.800	2.433	-0.006	0.059	-46.430	-13.961
	13.600	2.764	-0.009	0.039	-44.903	-12.145
	14.400	3.074	-0.007	0.010	-43.063	-10.284
	15.200	3.303	-0.006	-0.008	-41.074	-7.819
	16.000	3.394	-0.013	-0.031	-38.922	-5.337
	16.800	3.395	-0.015	-0.053	-36.645	-2.806
	17.600	3.359	-0.017	-0.074	-34.295	-2.277
	18.400	3.306	-0.010	-0.093	-31.929	2.317
	19.200	3.228	-0.014	-0.111	-29.601	4.965
	19.600	2.469	-0.026	-0.111	-29.264	6.125

SERIES I CASE 5 ZERO THRUST 15' WAVE

	TIME	NOSE GEAR	MAIN GEAR	MLS	GEAR LOAD	MGL	NGL
MINIMUM	0.000	5483.681	0.000	-63136.344	-42556.945	1.931	2.846
MAXIMUM	19.600	9920.370	33762.228	139677.025	-5483.681	13.492	7.560
	0.000	5483.681	0.000	139677.025	-5483.681	13.492	7.560
	0.800	9394.419	11821.203	34135.125	-22135.695	4.459	3.209
	1.600	8277.702	23887.125	-1922.944	-31184.820	2.616	3.549
	2.400	9149.032	31220.676	-56524.156	-39149.711	2.116	3.415
	3.200	8519.447	28612.052	-32354.500	-37121.122	2.422	3.147
	4.000	8870.342	25080.379	-5759.960	-34765.719	2.758	2.991
	4.800	9872.200	26620.477	-12042.944	-35492.734	2.619	3.354
	5.600	8744.412	31835.352	-52526.262	-42579.766	2.068	3.101
	6.400	9704.034	33762.228	-63136.344	-42556.945	1.931	3.132
	7.200	8903.[illegible]	33171.105	-33047.437	-39154.325	2.237	2.962
	8.000	9010.022	27570.025	-14873.156	-36537.523	2.585	2.947
	8.800	9334.012	27412.034	-15389.107	-36314.945	2.621	3.353
	9.600	5942.022	29146.733	-22420.252	-30989.625	2.530	3.148
	10.400	8334.955	27233.387	-16115.281	-30268.242	2.712	3.161
	11.200	8099.150	25153.068	-124.544	-34251.020	3.046	3.127
	12.000	9922.262	23020.437	11207.523	-32530.699	3.277	3.146
	12.800	8863.456	23020.480	14393.969	-31800.284	3.340	3.223
	13.600	8773.719	22842.855	13746.337	-31016.574	3.365	3.296
	14.400	8716.172	22392.344	15785.625	-31120.510	3.461	3.329
	15.200	8723.336	21559.141	21427.960	-32202.477	3.631	3.332
	16.000	9638.341	20793.719	26735.375	-29196.702	3.771	3.340
	16.800	9602.093	22424.445	23778.460	-29266.543	3.925	3.371
	17.600	8539.430	23291.107	28327.294	-28932.025	3.024	3.411
	18.400	8539.473	20185.215	27878.125	-29724.007	3.833	3.441
	19.200	9499.318	19912.633	23934.926	-28413.053	3.938	3.457
	19.600	9057.705	31119.434	-39171.531	-42177.141	2.143	2.846

SERIES I CASE 5 ZERO THRUST 15' WAVE (Cont'd)

	TIME	Z-FWD CP	Z-REAR CP
MINIMUM	0.000	-46.[illegible]	-44.177
MAXIMUM	19.600	-19.433	-22.927

TIME	Z-FWD CP	Z-REAR CP
0.000	-27.198	-2[illegible].253
0.800	-29.967	-28.775
1.600	-32.661	-31.244
2.400	-35.223	-33.612
3.200	-37.625	-35.330
4.000	-39.759	-37.853
4.800	-41.645	-39.055
5.600	-43.227	-41.100
6.400	-44.475	-42.430
7.200	-45.302	-43.351
8.000	-45.874	-43.933
8.800	-46.[illegible]	-44.177
9.600	-45.737	-44.064
10.400	-45.087	-43.598
11.200	-44.064	-42.789
12.000	-42.686	-41.051
12.800	-40.980	-4[illegible].275
13.600	-38.982	-36.482
14.400	-36.727	-36.515
15.200	-34.206	-34.345
16.000	-31.649	-32.017
16.800	-28.331	-29.582
17.600	-26.157	-27.064
18.400	-23.414	-24.582
19.200	-22.729	-22.123
19.600	-19.438	-22.927

SERIES I CASE 5 ZERO THRUST 15' WAVE (Cont'd)

	TIME	X A/C	Z(1) A/C	Z(1) S CG	Z-FWD CP	Z-REAR CP
MINIMUM	[illegible]	-1.637	-34.796	-1.592	-28.221	-28.221
MAXIMUM	58.881	1.266	-31.577	1.592	-24.805	-24.047
	0.000	-0.297	-33.520	0.000	-26.550	-26.482
	2.400	-1.637	-33.571	-0.669	-27.264	-27.134
	4.800	-0.269	-34.287	-1.213	-27.632	-27.671
	7.200	0.137	-34.343	-1.534	-28.150	-27.932
	9.600	-0.553	-34.710	-1.572	-28.100	-28.207
	12.000	1.042	[illegible]	-1.310	-27.677	-27.799
	14.400	-1.219	-33.987	-0.929	-27.331	-27.321
	16.800	1.327	-33.442	-0.475	-26.032	-26.301
	19.200	-0.308	-32.501	0.505	-25.028	-26.226
	21.600	0.031	-32.343	1.292	-25.200	-25.440
	24.000	0.163	-31.577	1.478	-24.032	-25.265
	26.000	-0.316	-31.836	1.598	-24.825	-24.047
	28.790	0.910	-31.063	1.410	-25.221	-25.115
	31.190	-1.227	-32.284	2.900	-25.517	-25.539
	33.600	2.354	-32.757	0.349	-26.192	-26.143
	36.000	-1.616	-33.324	-0.336	-26.013	-26.828
	38.400	0.061	-34.137	-0.350	-27.567	-27.410
	40.800	-0.009	-34.226	-1.420	-28.225	-27.360
	43.200	-0.248	-34.796	-1.592	-28.220	-28.052
	45.600	0.874	-34.357	-1.403	-28.362	-27.954
	48.000	-0.047	-34.321	-1.132	-27.630	-27.592
	50.421	1.477	-33.645	-0.517	-26.909	-27.224
	52.841	-1.033	-33.022	2.102	-26.271	-26.362
	55.231	1.151	-32.549	0.312	-25.365	-25.725
	57.601	-0.777	-31.782	1.312	-25.268	-25.231
	58.881	-0.923	-31.802	1.475	-24.034	-25.308

SERIES I CASE 6 ZERO THRUST 2.5' WAVE

	TIME	THETA DOT	THETA	MLG	NOSE GEAR	MAIN GEAR	GEAR LOAD
MINIMUM	0.000	-0.081	-0.023	-98373.187	5493.871	12493.600	-45367.005
MAXIMUM	60.001	0.103	0.025	61774.697	9415.061	37130.133	-15077.572
	0.000	0.001	0.003	35382.016	5493.371 3122.733	12493.600	-15077.573
	2.400	-0.058	0.019	-27638.405	9105.636	26780.223	-34880.759
	4.800	0.002	0.007	33051.159	8397.578	29700.359	-32262.747
	7.200	0.010	0.023	-87833.125	9172.210	35373.539	-44191.117
	9.600	-0.040	0.000	47970.094	8511.406	10133.363	-23345.379
	12.000	0.071	0.010	-29762.312	8631.443	28247.402	-36753.867
	14.400	-0.077	0.001	26037.713	9247.473	20040.207	-29527.052
	16.800	0.061	-0.010	28683.753	9242.335	21525.450	-30552.020
	19.200	-0.003	0.020	-42745.530	9415.061	23315.449	-37550.344
	21.600	0.021	-0.023	59423.037	9220.590	18223.371	-27624.332
	24.000	0.007	-0.002	-98373.137	9310.203	37130.120	-45367.005
	26.399	-0.024	-0.022	61140.234	8300.242	17031.590	-20397.973
	28.799	0.004	0.001	-57773.062	8962.235	31700.137	-40107.303
	31.199	-0.062	-0.007	45417.156	8734.152	18021.633	-27863.009
	33.600	0.077	0.022	1225.250	9120.238	24490.637	-33233.344
	36.000	-0.075	0.013	-104.503	9293.600	23752.977	-32190.215
	38.400	0.046	0.003	47203.231	9101.187	19577.239	-23872.727
	40.800	-0.027	0.025	-83540.219	9249.676	34012.156	-43201.344
	43.200	-0.009	0.001	61774.687	9284.117	17677.871	-27024.477
	45.600	0.047	0.018	-74560.562	9257.273	33032.679	-42216.727
	48.000	-0.059	-0.003	50434.078	9022.209	18462.253	-27519.332
	50.401	0.073	-0.001	-12746.873	9522.729	25000.053	-34409.219
	52.801	-0.031	-0.024	13110.344	9252.381	22223.758	-32746.403
	55.201	0.054	-0.013	30027.612	8212.777	22392.625	-20593.328
	57.601	-0.040	-0.022	-63082.375	8046.174	32230.992	-43419.773
	59.301	-0.066	-0.017	44375.844		19223.398	-27052.274

SERIES I CASE 6 ZERO THRUST 2.5' WAVE (Cont'd)

	TIME	NGL	NGL
MINIMUM	2.200	1.679	2.641
MAXIMUM	59.001	8.037	7.500
1	0.000	8.037	7.560
3	2.400	2.307	3.059
5	4.800	3.579	2.005
7	7.200	1.700	3.472
9	9.600	3.974	2.893
11	12.000	2.012	3.221
13	14.400	3.382	3.309
15	16.800	3.695	[illegible]
17	19.200	2.215	3.636
19	21.600	4.330	3.341
21	24.000	1.679	3.613
23	26.300	4.421	2.735
25	29.799	2.132	3.392
27	31.199	3.000	3.162
29	33.600	3.162	3.210
31	36.000	2.834	3.543
33	38.400	4.353	2.721
35	40.800	1.813	3.676
37	43.200	4.436	2.720
39	45.600	1.056	3.504
41	48.000	4.304	3.203
43	50.401	2.047	3.114
45	52.801	3.884	3.473
47	55.201	3.097	2.742
49	57.601	1.983	3.649
51	59.901	3.871	3.172

SERIES I CASE 6 ZERO THRUST 2.5' WAVE (Cont'd)

	TIME	X A/C	Z(1) A/C	Z(1) S CG	Z-FWD CP	Z-REAR CP
[illegible]	[illegible]	-1.067	-36.247	-3.199	-29.021	-29.031
[illegible]	58.921	1.692	-33.107	3.181	-23.111	-23.305
	[illegible]	-2.575	-33.500	2.322	[illegible]	-28.402
	2.4[illegible]	-1.222	-31.137	-1.337	-28.220	-27.769
	[illegible]	-1.597	-35.348	-2.420	-29.103	-28.542
	7.2[illegible]	-2.144	-35.762	-3.268	-29.020	-29.403
	9.6[illegible]	-2.579	-36.115	-3.144	-29.030	-29.574
	12.[illegible]	1.412	-35.582	-2.630	-29.254	-29.007
	14.4[illegible]	-2.791	-34.742	-1.647	-28.102	-29.141
	16.8[illegible]	1.400	-33.697	-3.351	-26.700	-26.692
	[illegible]	-2.422	-32.143	1.212	-25.016	-25.503
	21.6[illegible]	2.071	-31.398	2.134	-24.[illegible]	-24.386
	24.[illegible]	2.525	-32.237	2.055	-23.324	-23.632
	26.4[illegible]	-2.442	-32.357	3.101	-23.111	-23.305
	28.8[illegible]	[illegible]	-33.346	2.310	-23.543	-23.731
	31.2[illegible]	-1.474	-31.327	1.037	[illegible]	[illegible]
	33.6[illegible]	2.054	-32.366	0.697	-25.305	-25.782
	36.[illegible]	-1.097	-33.502	-0.071	-27.325	-27.115
	38.4[illegible]	2.204	-34.352	-1.316	-28.633	-28.300
	40.8[illegible]	-2.651	-35.466	-2.607	-29.548	-29.216
	43.2[illegible]	-2.226	-36.247	-3.179	-29.000	-29.509
	45.6[illegible]	1.115	-35.775	-2.965	-29.023	-29.427
	48.021	-2.615	-35.356	-2.233	-28.771	-28.070
	50.421	1.692	-34.222	-1.235	-27.490	-27.548
	52.821	-2.832	-32.688	0.325	-26.243	-26.224
	55.221	1.230	-31.379	1.024	-24.671	-24.051
	57.621	-2.230	-32.532	2.624	-23.038	-23.064
	58.921	-2.951	-33.513	2.051	-23.012	-23.039

SERIES I CASE 7 ZERO THRUST 5' WAVE

	TIME	NOSE GEAR	MAIN GEAR	GEAR LOAD	THETA DOT	THETA	ALG
MINIMUM	0.000	5480.071	9950.264	-45220.572	-0.281	-0.030	-99477.025
MAXIMUM	58.881	9413.141	36052.328	-15442.135	0.103	0.238	92112.734
	0.000	5433.871	9950.204	-15442.135	0.002	0.006	30187.202
	2.400	8122.340	20370.031	-34979.383	-0.251	0.003	-20235.344
	4.800	3204.035	21791.887	-33870.523	-0.004	0.001	27070.030
	7.200	8321.576	34772.773	-43152.231	0.012	0.005	-78545.262
	9.600	9115.402	21325.072	-38421.164	-0.040	0.017	31405.000
	12.000	3055.293	27792.034	-30447.077	0.000	0.010	-23006.344
	14.400	5015.077	32000.055	-31303.032	-0.277	0.004	11720.252
	16.800	9180.270	22300.227	-23751.406	0.252	-0.016	38177.757
	19.200	3017.323	32296.777	-42314.506	-0.252	-0.003	-62393.050
	21.600	9113.141	17034.754	-27253.805	0.010	-0.030	92112.734
	24.000	9257.244	36052.328	-45220.572	0.221	-0.013	-99477.025
	26.400	3233.314	17733.309	-27020.025	-0.231	-0.032	62314.437
	28.800	8412.345	33324.281	-39310.032	0.271	-0.028	-52540.437
	31.200	3932.214	19139.182	-28261.413	-0.263	-0.008	42341.437
	33.600	9782.422	21313.328	-32795.753	0.278	0.005	5634.303
	36.000	9306.437	24472.094	-32939.422	-0.272	0.222	-5042.232
	38.400	9317.919	19293.493	-29078.321	0.242	0.014	40773.752
	40.800	9173.187	35033.061	-40934.149	-0.217	0.232	-80804.713
	43.200	3230.334	17727.211	-27027.227	-0.217	0.213	62491.223
	45.600	3313.233	32241.494	-42554.791	0.254	0.225	-62262.875
	48.021	3936.249	19970.422	-27311.672	-0.203	0.023	44251.375
	50.401	9745.753	21[illegible].974	-32939.339	0.260	-0.025	3911.713
	52.[illegible]	8339.324	24244.682	-32641.586	-0.231	-0.029	-3714.252
	55.221	9322.211	10445.823	-28703.031	0.242	-0.231	40707.731
	57.621	8219.731	34922.703	-43139.404	-0.233	-0.013	-92917.156
	59.331	9941.654	10638.339	-20443.005	-0.272	-0.226	33020.156

SERIES I CASE 7 ZERO THRUST 5' WAVE (Cont'd)

	TIME	Y A/C	Z(1) A/C	Z(1) S CG	THETA DOT	THETA	SIG
MINIMUM	0.202	-2.576	-44.327	-12.101	-0.351	-0.100	-52075.002
MAXIMUM	58.221	2.835	-22.344	12.184	0.204	0.120	50547.617
	2.002	-2.281	-33.522	0.822	0.026	0.023	50547.617
	2.400	-2.576	-37.220	-5.110	-0.020	0.202	-52075.502
	4.300	-2.242	-41.272	-0.204	0.020	0.125	2000.000
	7.2..	-0.411	-43.620	-11.752	0.015	0.120	-49002.125
	9.600	0.420	-44.130	-12.842	-0.025	0.200	-36512.125
	12.000	1.612	-42.025	-12.120	0.010	0.252	-18123.007
	14.400	2.420	-39.310	-6.300	0.006	0.270	-11461.156
	16.900	2.636	-34.337	-1.344	0.012	-0.239	3714.719
	19.202	2.714	-32.126	0.000	0.212	-0.077	12382.731
	21.600	2.257	-29.910	3.307	0.217	-0.122	19532.875
	24.000	1.476	-23.046	11.323	0.221	-0.127	21013.522
	26.400	0.573	-22.344	12.184	0.226	0.204	25722.097
	28.800	-0.321	-23.378	13.709	0.232	-0.263	20263.075
	31.200	-1.243	-25.088	7.422	0.232	-0.221	27582.731
	33.600	-1.521	-32.231	2.671	0.228	0.024	23222.031
	36.000	-1.729	-35.021	-2.571	0.219	0.265	23073.531
	38.400	-1.634	-30.450	-7.033	0.025	0.293	23005.219
	41.000				-0.314	0.124	20002.156
	43.200	-2.827	-44.225	-12.179	-0.231	0.200	22302.504
	45.600	-2.159	-43.081	-11.358	-0.344	0.270	10032.344
	48.021	0.510	-41.102	-8.443	-0.243	0.002	700.344
	50.421	1.300	-37.212	-3.034	-0.345	-0.212	-13477.433
	52.821	1.351	-32.479	1.244	-0.236	-0.254	-26270.156
	55.221	1.333	-27.974	0.223	-0.222	-0.235	-30341.000
	57.621	0.000	-24.235	10.252	-0.327	-0.122	-41361.437
	50.021	1.024	-23.201	11.023	0.223	-0.100	31102.437

SERIES I CASE 8 ZERO THRUST 10' WAVE

	TIME	Z-FWD CP	Z-REAR CP	NOSE GEAR	MAIN GEAR	GEAR LOAD
MINIMUM	0.000	-39.556	-38.312	5483.871	7524.239	-41116.477
MAXIMUM	58.801	-13.528	-14.705	9147.789	32220.504	-12938.260
	0.000	-26.905	-26.335	5480.871	7524.239	-12938.000
	2.400	-32.437	-31.327	9198.323	33316.663	-30534.000
	4.800	-36.745	-35.414	3933.237	25503.676	-34493.983
	7.200	-39.195	-37.859	9915.073	32220.574	-41116.477
	9.600	-39.311	-38.217	9232.564	30007.145	-39097.711
	12.000	-37.307	-36.417	9147.789	29443.420	-37591.219
	14.400	-32.869	-32.793	9207.932	27232.738	-36322.572
	16.800	-27.405	-27.908	9209.932	24870.793	-33975.625
	19.200	-21.047	-22.020	8904.352	23941.272	-32035.617
	21.600	-17.252	-18.541	9952.861	22531.905	-31494.828
	24.000	-14.266	-15.624	3361.971	21934.108	-32736.233
	26.400	-13.528	-14.725	8825.333	21297.538	-33122.073
	28.800	-15.178	-15.057	8775.132	21137.278	-29932.102
	31.200	-18.921	-19.157	8722.910	22745.308	-29468.329
	33.600	-24.265	-23.715	8637.670	23320.289	-28936.931
	36.000	-29.651	-28.782	8437.992	19644.531	-28092.523
	38.400	-34.641	-33.410	9249.408	19153.129	-27398.530
	40.800	-38.124	-36.759	9157.932	19232.695	-27392.578
	43.200	-39.469	-38.222	8177.213	19941.191	-28118.426
	45.600	-38.427	-37.532	9265.299	21429.789	-29695.278
	48.001	-35.184	-34.932	8416.926	23076.503	-32303.330
	52.401	-30.334	-30.536	3604.867	20211.129	-34816.000
	52.801	-24.792	-25.533	3797.290	20562.441	-37359.742
	55.201	-19.557	-20.717	8071.646	32434.007	-39426.711
	57.601	-15.625	-16.379	9117.309	31639.063	-40757.231
	53.801	-14.377	-15.736	9485.961	19570.841	-28264.022

SERIES I CASE 8 ZERO THRUST 10' WAVE (Cont'd)

	TIME	MGL	MGL
MINIMUM	0.000	2.064	2.022
MAXIMUM	58.801	11.514	7.502

0.000	11.514	7.502
2.400	2.103	3.307
4.800	2.737	2.955
7.200	2.25[illegible]	2.953
9.600	2.212	2.930
12.000	2.520	2.902
14.400	2.693	2.994
16.800	3.007	2.933
19.200	3.226	3.000
21.600	3.453	3.142
24.000	3.540	3.212
26.400	3.654	3.235
28.800	3.678	3.297
31.200	3.747	3.320
33.600	3.819	3.302
36.000	3.945	3.510
38.400	4.033	3.637
40.800	3.939	3.330
43.200	3.739	3.640
45.600	3.349	3.408
48.001	2.939	3.327
50.401	2.631	3.129
52.801	2.358	2.986
55.201	2.195	2.973
57.601	2.121	2.022
58.801	3.942	3.446

SERIES I CASE 8 ZERO THRUST 10' WAVE (Cont'd)

[illegible]	TIME	X A/C	Z(I) A/C	Z(I) S CG	Z-FWD CP	Z-REAR CP
[illegible]	[illegible]	-5.523	-62.400	-32.404	-58.565	-55.456
[illegible]	[illegible]	5.527	-6.261	32.402	4.853	1.913
	[illegible]	[illegible]	-33.592	[illegible]	-27.664	-26.298
	[illegible]	-4.529	-43.439	-12.703	-41.125	-38.425
	[illegible]	-3.322	-53.268	-23.235	-51.097	-48.371
	[illegible]	[illegible]	[illegible]	-29.331	-57.040	-54.329
	[illegible]	[illegible]	-62.435	-32.134	-58.210	-55.292
	[illegible]	1.373	-50.821	-25.269	-52.340	-51.323
	[illegible]	3.209	-48.587	-15.772	-42.391	-42.175
	[illegible]	4.273	-37.861	-3.359	-29.189	-30.422
	[illegible]	[illegible]	-25.581	9.671	-15.648	-18.132
	[illegible]	[illegible]	-15.925	22.317	-4.337	-7.529
	[illegible]	[illegible]	-8.573	28.331	2.015	-2.491
	[illegible]	[illegible]	-6.261	32.402	4.853	1.913
	[illegible]	[illegible]	-6.404	26.997	1.116	-2.832
	[illegible]	-2.912	-13.219	13.592	-7.748	-6.339
	[illegible]	-3.333	-25.319	0.673	-20.117	-19.242
	[illegible]	[illegible]	-36.756	-6.420	-33.552	-31.372
	[illegible]	[illegible]	-47.376	-18.340	-45.472	-42.393
	[illegible]	[illegible]	-55.253	-28.379	-53.012	-52.393
	[illegible]	-1.451	-59.253	-32.448	-57.224	-54.113
	[illegible]	[illegible]	-58.104	-29.394	-55.127	-52.865
	[illegible]	[illegible]	-52.746	-21.399	-47.713	-46.757
	[illegible]	4.728	-43.593	-5.929	-36.346	-36.852
	[illegible]	[illegible]	-32.934	3.111	-23.228	-25.124
	[illegible]	[illegible]	[illegible]	15.550	-12.511	-13.312
	[illegible]	[illegible]	-13.516	25.132	-1.598	-4.985
	[illegible]	[illegible]	-13.305	23.255	1.422	-1.975

SERIES I CASE 9 ZERO THRUST 25' WAVE

	TIME	THETA_DOT	THETA	XLC	NOSE GEAR	MAIN GEAR	GEAR LOAD
MINIMUM	0.000	-0.277	-0.255	-57542.781	5400.001	0.000	-42973.320
MAXIMUM	50.321	0.277	0.204	129877.825	9306.512	31875.012	-5403.391
	[illegible]	[illegible]	0.253	129877.825	5400.001	0.000	-5403.391
	[illegible]	[illegible]	0.316	-57542.781	8371.259	31774.843	-42143.103
	4.[illegible]	[illegible]	0.264	-36560.050	8482.775	29122.051	-37002.929
	[illegible]	[illegible]	0.257	21205.426	8433.200	27817.272	-20290.477
	[illegible]	-[illegible]	0.211	24325.201	7022.000	19005.780	-26020.000
	[illegible]	-[illegible]	0.126	18233.213	8235.103	22108.734	-29143.914
	[illegible]	-[illegible]	0.716	6765.219	3350.936	22369.137	-33720.274
	[illegible]	-[illegible]	-0.292	-12723.719	8546.170	25220.200	-34482.234
	[illegible]	-[illegible]	-0.180	-23715.312	9939.227	29725.842	-37205.247
	[illegible]	-[illegible]	-0.255	-43723.312	9297.938	31375.012	-40973.320
	[illegible]	[illegible]	-0.253	-31757.420	9223.285	32522.437	-39729.727
	[illegible]	[illegible]	-0.220	-22[illegible].531	9273.205	29228.440	-38221.742
	[illegible]	[illegible]	-0.149	-15540.262	9372.337	26073.125	-30246.016
	[illegible]	[illegible]	-0.244	-22812.781	9306.512	29455.210	-38551.727
	[illegible]	[illegible]	0.372	-21772.281	9269.502	29257.055	-33526.945
	[illegible]	[illegible]	0.172	-13224.420	8062.844	26757.233	-35718.236
	[illegible]	[illegible]	0.236	14027.212	8153.279	21016.242	-38256.523
	[illegible]	-[illegible]	0.263	26222.994	7949.524	10458.069	-20328.492
	[illegible]	-[illegible]	0.243	14361.325	7934.027	22214.422	-29293.410
	[illegible]	-[illegible]	0.179	-22335.437	8387.461	26325.733	-35103.223
	[illegible]	-[illegible]	0.279	-41127.752	8546.611	31002.337	-42237.222
	[illegible]	-[illegible]	-[illegible]	-33773.137	9157.324	32630.371	-39795.695
	[illegible]	-[illegible]	-0.143	-19132.520	9166.062	23537.754	-37764.734
	[illegible]	[illegible]	-0.224	342.219	9242.434	25424.937	-[illegible]445.325
	[illegible]	[illegible]	-0.264	13245.275	[illegible].457	22153.274	-33962.531
	[illegible]	-[illegible]	-0.259	-23756.531	9008.432	27524.961	-36223.391

SERIES I CASE 9 ZERO THRUST 25' WAVE (Cont'd)

	TIME	MOL	MOL
MINIMUM	[illegible]	2.391	2.637
MAXIMUM	[illegible]	17.446	7.563
[illegible]	[illegible]	17.440	7.533
[illegible]	[illegible]	2.122	3.218
[illegible]	[illegible]	2.373	3.427
7	[illegible]	3.784	3.507
[illegible]	[illegible]	4.377	3.541
[illegible]	[illegible]	3.679	3.730
[illegible]	[illegible]	3.137	3.333
[illegible]	[illegible]	2.029	3.173
[illegible]	[illegible]	2.324	2.974
[illegible]	[illegible]	2.791	2.852
[illegible]	[illegible]	2.245	2.796
[illegible]	[illegible]	2.442	2.772
[illegible]	[illegible]	2.496	2.713
[illegible]	[illegible]	2.435	2.987
[illegible]	[illegible]	2.425	2.781
[illegible]	[illegible]	2.768	3.259
[illegible]	[illegible]	3.591	3.561
[illegible]	[illegible]	4.215	4.231
[illegible]	[illegible]	3.626	3.999
[illegible]	[illegible]	2.569	3.363
[illegible]	[illegible]	2.166	2.384
[illegible]	[illegible]	2.233	2.837
[illegible]	52.521	2.522	2.993
[illegible]	[illegible]	2.377	3.227
[illegible]	[illegible]	2.519	3.257
[illegible]	[illegible]	2.471	3.309

SERIES I CASE 9 ZERO THRUST 25' WAVE (Cont'd)

	TIME	U A C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	4.295	-0.062	-0.006	-0.953	-49.890
MAXIMUM	14.700	0.017	2.897	0.115	0.157	0.072	-34.000
	0.000	0.000	-3.153	0.012	-0.006	0.000	-34.000
	0.600	0.017	-4.256	-0.089	0.033	-0.003	-34.597
	1.200	0.017	-1.340	0.115	0.003	-0.005	-36.971
	1.800	0.017	-4.295	-0.067	0.031	-0.049	-38.448
	2.400	0.017	-1.541	0.091	0.057	-0.083	-39.927
	3.000	0.017	-2.468	0.017	0.054	-0.181	-41.663
	3.600	0.017	-2.935	-0.009	0.085	-0.256	-42.831
	4.200	0.017	1.477	0.063	0.087	-0.368	-44.334
	4.800	0.017	-2.408	-0.026	0.101	-0.480	-45.537
	5.400	0.017	-1.110	0.054	0.118	-0.570	-46.609
	6.000	0.017	-1.570	0.005	0.116	-0.697	-47.644
	6.600	0.017	-1.467	-0.002	0.138	-0.750	-48.219
	7.200	0.017	-0.456	0.039	0.134	-0.856	-49.009
	7.800	0.017	-1.500	-0.033	0.144	-0.903	-49.401
	8.400	0.017	0.297	0.044	0.150	-0.927	-49.645
	9.000	0.017	-0.361	0.019	0.144	-0.953	-49.890
	9.600	0.017	0.297	0.004	0.157	-0.903	-49.626
	10.200	0.017	0.932	0.014	0.144	-0.835	-49.575
	10.800	0.017	0.257	-0.040	0.150	-0.793	-49.032
	11.400	0.017	1.744	0.031	0.143	-0.706	-48.491
	12.000	0.017	2.081	-0.043	0.134	-0.596	-47.806
	12.600	0.017	1.998	0.009	0.136	-0.444	-46.741
	13.200	0.017	1.976	-0.011	0.116	-0.326	-45.894
	13.800	0.017	1.561	-0.047	0.117	-0.154	-44.532
	14.400	0.017	2.897	0.019	0.100	-0.017	-43.310
	14.700	0.017	2.310	-0.022	0.102	0.072	-42.491

SERIES I CASE 10

	TIME	MGL	NGL	NOSE GEAR	MAIN GEAR
MINIMUM	0.000	0.912	2.699	0.000	0.000
MAXIMUM	14.700	12.000	12.000	9626.010	52716.547
	0.000	12.000	12.000	0.000	0.000
	0.600	0.912	0.490	8678.461	52716.547
	1.200	5.175	2.737	9050.169	17294.270
	1.800	3.926	3.434	8635.064	17527.160
	2.400	2.102	3.410	8321.979	32736.387
	3.000	4.207	2.839	9204.348	18493.895
	3.600	2.511	3.693	8164.215	29007.871
	4.200	3.504	3.043	8807.054	22549.691
	4.800	3.342	3.315	8654.854	21962.922
	5.400	2.497	3.005	8311.602	29268.852
	6.000	3.810	3.045	8905.893	19351.099
	6.600	2.425	3.631	8176.520	28711.602
	7.200	3.464	3.129	8751.895	21719.941
	7.800	3.096	3.455	8467.892	23108.895
	8.400	2.740	3.475	8342.141	20108.641
	9.000	3.720	3.166	8777.318	20388.336
	9.600	2.351	3.669	8184.391	29280.426
	10.200	3.041	3.095	8935.229	20899.797
	10.800	2.825	3.566	8330.006	25329.801
	11.400	3.072	3.357	8463.730	24158.936
	12.000	3.527	3.213	8742.008	21275.332
	12.600	2.583	3.539	8261.311	29096.969
	13.200	3.772	3.023	8913.662	20251.531
	13.800	2.590	3.559	8314.010	26964.285
	14.400	3.144	3.162	8690.592	23719.[illegible]
	14.700	2.359	3.583	8297.726	23594.657

SERIES I CASE 10 (Cont'd)

	TIME	Z(I) S CG	Z-FWD CP	Z-REAR CP
MINIMUM	0.000	-18.296	-46.139	-44.230
MAXIMUM	14.700	0.000	-26.389	-26.033
	0.000	0.000	-26.399	-26.557
	0.600	-1.889	-28.424	-28.375
	1.200	-3.757	-30.438	-30.193
	1.800	-5.585	-32.410	-31.[illegible]
	2.400	-7.354	-34.318	-33.[illegible]97
	3.000	-9.044	-36.140	-35.[illegible]26
	3.600	-10.639	-37.859	-36.370
	4.200	-12.118	-39.453	-38.301
	4.800	-13.469	-40.909	-39.624
	5.400	-14.675	-42.210	-40.707
	6.000	-15.725	-43.341	-41.775
	6.600	-15.027	-44.294	-42.623
	7.200	-17.312	-45.055	-43.296
	7.800	-17.831	-45.620	-43.792
	8.400	-19.161	-45.984	-44.105
	9.000	-18.296	-46.139	-44.230
	9.600	-18.256	-46.088	44.171
	10.200	-17.991	-45.827	-43.921
	10.800	-17.535	-45.365	-43.490
	11.400	-16.901	-44.700	-42.877
	12.000	-16.087	43.842	-42.090
	12.600	-15.100	-42.801	-41 139
	13.200	-13.953	41.593	-40.029
	13.800	-12.656	-40.225	-38.774
	14.400	-11.225	-38.678	-37.386
	14.700	-10.463	-37.865	-36.645

SERIES I CASE 10 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-2.539	-0.039	-0.010	-100.566	-42.840
MAXIMUM	14.700	0.000	1.744	0.009	0.153	-99.965	-33.500
	0.000	0.000	-1.937	0.012	-0.006	-100.000	-33.500
	0.600	0.000	-0.684	0.008	0.006	-99.991	-34.721
	1.200	0.000	-1.155	0.035	0.017	-100.006	-35.942
	1.800	0.000	-1.965	0.009	0.034	-100.032	-36.764
	2.400	0.000	-1.931	0.012	0.052	-100.065	-37.582
	3.000	0.000	-1.021	0.037	0.058	-100.100	-38.433
	3.600	0.000	-0.922	0.035	0.076	-100.175	-39.533
	4.200	0.000	-1.583	0.005	0.089	-100.240	-40.091
	4.800	0.000	-1.375	0.009	0.105	-100.233	-40.541
	5.400	0.000	-0.427	0.035	0.114	-100.358	-41.241
	6.000	0.000	-0.500	0.018	0.121	-100.427	-41.920
	6.600	0.000	-1.031	-0.003	0.131	-100.474	-42.184
	7.200	0.000	-0.571	0.007	0.140	-100.507	-42.412
	7.800	0.000	0.207	0.024	0.144	-100.541	-42.653
	8.400	0.000	0.002	0.008	0.145	-100.566	-42.840
	9.000	0.000	-0.475	-0.018	0.149	-100.557	-42.792
	9.600	0.000	0.312	0.004	0.155	-100.527	-42.607
	10.200	0.000	0.912	0.014	0.148	-100.506	-42.490
	10.800	0.000	0.445	-0.012	0.145	-100.466	-42.252
	11.400	0.000	0.315	-0.022	0.144	-100.398	-41.759
	12.000	0.000	1.235	-0.003	0.159	-100.325	-41.234
	12.600	0.000	1.439	0.000	0.130	-100.256	-40.732
	13.200	0.000	0.963	-0.025	0.120	-100.177	-40.111
	13.800	0.000	0.949	-0.035	0.114	-100.078	-39.269
	14.400	0.000	1.744	-0.004	0.103	-99.992	-38.472
	14.700	0.000	0.941	-0.039	0.096	-99.955	-38.105

SERIES I CASE 11

	TIME	Z-[illegible] CG	Z-FWD CP	Z-REAR CP	NOSE GEAR	MAIN GEAR	ZLG
MINIMUM	0.000	-19.2[illegible]	-39.121	-37.219	9197.795	16168.041	-125234.87
MAXIMUM	14.700	0.000	-26.044	-27.095	12631.736	112653.141	-24365.855
	0.000	0.010	-26.314	-27.095	12631.736	112653.141	-125234.87
	0.500	-1.[illegible]	-24.218	-28.200	9436.932	30367.703	-40354.539
	1.200	-3.[illegible]97	-29.533	-29.287	8709.414	21132.414	-29841.828
	1.[illegible]00	-5.[illegible]	-30.790	-30.344	8331.055	21290.[illegible]55	-29611.910
	2.[illegible]00	-7.504	-31.470	-31.560	8806.816	26773.092	-35585.812
	3.000	-[illegible].744	-33.137	-32.323	8983.203	28132.660	-37115.867
	3.[illegible]00	-10.[illegible]	-34.211	-33.222	8534.113	22077.691	-30611.805
	[illegible].700	-12.114	-35.221	-34.049	8407.810	21284.047	-29691.887
	4.[illegible]00	-13.10[illegible]	-36.099	-34.794	8761.125	27707.703	-36468.828
	5.400	-14.07[illegible]	-36.803	-35.450	8646.598	26459.199	-35285.891
	6.000	-15.725	-37.575	-36.010	8424.355	21564.129	-29788.484
	6.500	-15.027	-38.140	-36.469	8372.593	22592.148	-30964.043
	7.200	-17.312	-38.081	-36.822	8829.367	27789.543	-36618.914
	7.[illegible]00	-17.431	-38.833	-37.064	8729.268	25620.273	-34349.539
	8.400	-1[illegible].161	-39.073	-37.134	8323.059	20950.316	-29273.375
	9.000	-14.236	-39.121	-37.213	8424.549	22819.629	-31244.180
	9.600	-14.2[illegible]	-39.035	-37.118	8811.475	23705.547	-37519.023
	10.200	-17.961	-38.315	-36.909	8655.205	23762.680	-32417.837
	10.900	-17.535	-38.405	-36.591	8299.660	21103.937	-29403.598
	11.400	-16.901	-37.939	-36.16[illegible]	8526.467	24775.652	-33300.117
	12.000	-16.047	-37.540	-35.638	8877.229	27823.215	-36700.445
	12.600	-15.100	-35.674	-35.012	857[illegible].053	23307.316	-31894.371
	13.200	-13.903	-35.850	-34.295	8379.406	21259.539	-29637.945
	13.900	-12.465	-34.929	-33.496	8672.221	25853.164	-34522.583
	14.400	-11.225	-33.911	-32.620	8901.912	27705.480	-36607.391
	14.700	-10.455	-33.372	-32.156	8508.512	23437.203	-31945.715

SERIES I CASE 11 (Cont'd)

	TIME	NGL	NGL
MINIMUM	0.000	0.000	0.894
MAXIMUM	14.700	4.963	4.073

0.000	0.000	0.894
0.600	2.301	2.616
1.200	3.651	3.337
1.800	3.500	3.511
2.400	2.613	3.052
3.000	2.505	2.939
3.600	3.425	3.378
4.200	3.497	3.440
4.800	2.511	3.119
5.400	2.756	3.108
6.000	3.537	3.466
6.600	3.242	3.455
7.200	2.517	3.043
7.800	2.349	3.222
8.400	3.617	3.545
9.000	3.175	3.395
9.600	2.415	3.110
10.200	3.145	3.292
10.800	3.577	3.563
11.400	2.937	3.303
12.000	2.523	3.059
12.600	3.206	3.355
13.200	3.537	3.483
13.800	2.756	3.194
14.400	2.551	3.045
14.700	3.086	3.330

SERIES I CASE 11 (Cont'd)

SERIES II NO WAVE MOTION

CASE	THRUST	θ_t	K_R	K_P
1	33600	-.014	.4	.8
2	33650	-.014	.4	.8
3	33650	-.0223	.2	.4
4	33700	-.035	.4	.8
5	33750	-.032	.4	.8
6	33750	-.0215	.4	.8
9	33800	-.0275	.4	.8
10	33800	-.0198	.4	.8
11	33800	-.0205	.4	.8
14	33850	-.0190	.4	.8
15	33850	-.0192	.4	.6
16	33850	-.0200	.3	.6

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-2.031	-2.722	-0.145	-0.052	-1.377	-21.454
MAXIMUM	14.700	[illegible]	2.420	0.133	0.030	31.360	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-0.127	-1.825	0.007	-0.004	-0.053	-34.449
	1.200	[illegible]	-1.804	0.013	0.009	-0.524	-35.554
	1.800	0.312	-1.[illegible]	[illegible]	-0.012	-0.367	-36.659
	2.400	-2.004	-1.[illegible]	0.096	0.004	-0.837	-37.720
	3.000	1.441	-1.319	-0.101	0.016	-1.303	-38.669
	3.600	0.342	-1.251	-0.033	-0.049	-0.292	-39.429
	4.200	-2.2[illegible]	-1.041	0.134	-0.017	-0.764	-40.109
	4.800	1.114	-0.[illegible]	-0.052	0.025	-1.258	-40.685
	5.400	[illegible]	-0.59[illegible]	-0.073	-0.043	0.291	-41.026
	6.000	-0.874	-0.550	0.111	-0.031	0.649	-41.282
	6.600	1.[illegible]	-0.049	-0.001	0.023	0.356	-41.454
	7.200	5.422	0.039	-0.109	-0.033	2.284	-41.383
	7.800	0.027	0.321	0.077	-0.042	5.476	-41.215
	8.400	1.2[illegible]	0.571	0.049	0.025	3.543	-40.974
	9.000	4.8[illegible]	0.812	-0.139	-0.019	5.632	-40.500
	9.600	2.091	0.957	0.043	-0.049	7.712	-39.909
	10.200	1.22[illegible]	1.182	0.100	0.017	8.300	-39.243
	10.800	0.721	1.629	-0.142	-0.003	10.507	-38.376
	11.400	3.4[illegible]	1.549	0.008	-0.002	13.352	-37.358
	12.000	1.453	1.858	0.133	0.004	14.613	-36.260
	12.600	[illegible]	2.426	-0.114	0.012	16.819	-35.006
	13.200	[illegible]	0.998	0.128	0.006	20.494	-34.006
	13.800	[illegible]	-1.929	-0.115	0.004	[illegible]	-33.710
	14.400	[illegible]	-2.574	0.050	-0.018	29.616	-35.213
	14.700	[illegible]	-2.542	0.102	0.008	31.360	-35.942

SERIES II CASE 1

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-2.231	-1.962	-0.169	-0.067	-1.605	-43.703
MAXIMUM	14.699	8.755	1.363	0.163	0.038	33.652	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-0.341	-1.951	0.000	-0.005	-0.042	-34.459
	1.200	-0.822	-1.428	0.025	0.009	-0.493	-35.588
	1.800	0.743	-1.912	-0.062	-0.004	-0.538	-36.746
	2.400	-1.401	-1.812	0.060	-0.015	-0.488	-37.904
	3.000	-0.704	-1.763	0.018	0.00[illegible]	-1.605	-39.002
	3.600	2.112	-1.508	-0.157	-0.026	-0.768	-39.913
	4.200	-0.217	-1.340	0.026	-0.066	-0.100	-40.748
	4.800	-2.040	-1.316	0.159	0.002	-0.912	-41.538
	5.400	2.332	-0.811	-0.086	0.029	-0.922	-42.213
	6.000	2.570	-0.474	-0.094	-0.054	1.081	-42.679
	6.600	0.174	-0.653	0.092	-0.053	1.950	-43.095
	7.200	0.135	-0.535	0.092	0.029	1.685	-43.474
	7.800	4.322	-0.287	-0.159	0.003	3.383	-43.648
	8.399	5.031	-0.245	-0.030	-0.066	5.971	-43.696
	[illegible]	0.502	0.219	0.149	-0.028	7.075	-43.696
	9.599	5.311	0.420	-0.001	0.038	7.831	-43.634
	10.199	5.144	0.372	-0.152	-0.031	11.104	-43.337
	10.799	3.567	0.417	0.033	-0.066	13.959	-42.969
	11.399	1.745	0.633	0.158	0.004	15.309	-42.557
	11.999	6.178	1.329	-0.093	0.028	17.684	-42.023
	12.599	6.409	0.318	-0.039	-0.055	21.954	-41.284
	13.199	5.375	1.144	0.096	-0.052	25.042	-40.495
	13.799	4.271	1.622	0.086	0.030	27.040	-39.569
	14.399	8.735	1.913	-0.162	0.001	31.060	-38.635
	14.699	9.142	1.562	-0.118	-0.045	33.652	-38.059

SERIES II CASE 2

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
[illegible]	0.000	-4.0[illegible]	-1.950	-0.265	-0.152	-6.254	-38.9[illegible]
[illegible]	14.6[illegible]	5.117	1.748	0.271	0.109	4.363	-33.045
	0.000	0.000	0.000	0.000	0.000	0.000	-33.000
	0.600	0.000	-1.[illegible]	-0.085	0.005	0.002	-33.083
	1.200	0.000	0.992	0.069	0.004	0.004	-33.576
	1.800	0.000	-0.[illegible]52	-0.050	0.028	0.008	-33.[illegible]
	2.400	0.000	-0.[illegible]	-0.021	0.004	-0.003	-33.730
	3.000	0.14[illegible]	0.7[illegible]	0.025	0.006	0.059	-33.825
	3.600	0.107	-0.315	-0.007	0.001	0.124	-34.010
	4.200	-0.450	0.425	0.002	0.003	0.055	-33.795
	4.800	-1.[illegible]	-0.[illegible]21	0.019	0.002	-0.5[illegible]	-34.256
	5.400	-2.01[illegible]	-1.050	0.044	0.027	-1.4[illegible]	-34.828
	6.000	-0.1[illegible]	-0.[illegible]	-0.077	0.021	-2.255	-35.417
	6.600	-0.0[illegible]	-0.[illegible]	-0.077	-0.042	-2.041	-36.002
	7.200	-2.[illegible]	-0.774	0.109	-0.031	-2.904	-36.555
	7.800	-5.[illegible]	-1.075	0.139	0.064	-5.196	-37.057
	8.400	0.210	-0.517	-0.151	0.0[illegible]	-6.219	-37.466
	9.000	1.[illegible]	-0.[illegible]	-0.216	-0.0[illegible]7	-5.238	-37.717
	9.600	0.2[illegible]	-0.460	-0.031	-0.139	-4.[illegible]72	-37.9[illegible]
	10.200	-0.[illegible]	-0.574	0.155	-0.100	-4.325	-38.22[illegible]
	10.800	-2.0[illegible]	-0.[illegible]	0.245	0.057	-5.917	-38.508
	11.400	1.[illegible]	-0.060	-0.016	0.106	-6.039	-38.716
	12.000	3.112	0.0[illegible]	-0.2[illegible]	0.015	-3.933	-38.771
	12.600	5.[illegible]	-0.4[illegible]	-0.146	-0.121	-1.117	-38.754
	13.200	5.047	-0.517	0.039	-0.152	0.967	-38.775
	13.800	1.0[illegible]	-0.207	0.224	-0.072	2.471	-38.919
	14.400	2.413	0.168	0.180	0.076	3.555	-38.959
	14.6[illegible]	4.217	0.573	0.014	0.109	4.363	-38.952

SERIES II CASE 3

	TIME	MZ	BIS	XF	NOSE GEAR	MAIN GEAR
MINIMUM	0.000	-55049.977	-0.192	-6421.178	0.000	0.000
MAXIMUM	14.400	0.000	0.284	9428.648	8615.158	29267.129
	0.000	0.000	0.000	0.000	5485.871	11091.232
	0.600	-6324.019	0.013	79.721	7930.397	19580.172
	1.200	-12374.022	-0.059	-481.734	5380.436	13504.104
	1.800	-17[illegible].004	0.122	2201.352	4606.175	15051.064
	2.400	-24[illegible]1.245	0.054	1241.372	3247.401	5956.949
	3.000	-22210.[illegible]	0.050	820.594	0.000	8173.736
	3.600	-30445.500	-0.016	-480.036	0.000	0.000
	4.200	-42[illegible].555	-0.058	-1255.209	4353.463	9024.442
	4.800	-55396.524	-0.072	-2419.235	0.000	0.000
	5.400	-55[illegible].915	0.061	2066.050	0.000	0.000
	6.000	-55555.703	0.137	4598.495	0.000	0.000
	6.600	-55051.004	-0.192	-6421.178		
	7.200	-45074.052	-0.185	-6185.051		
	7.800	-3[illegible].141	0.247	8257.[illegible]		
	8.400	-32[illegible]7.175	0.280	9505.244		
	9.000	-55051.004	-0.192	-6421.178		
	9.600	-55051.004	-0.192	-6421.178		
	10.200	-55051.004	-0.192	-6421.178		
	10.800	-55104.273	0.180	6065.502		
	11.400	-32422.062	0.284	9428.648		
	12.000	-55470.062	0.105	3475.229		
	12.600	-55051.004	-0.192	-6421.178		
	13.200	-55051.004	-0.192	-6421.178		
	13.800	-55144.414	-0.174	-5811.196		
	14.361	-32322.062	0.284	9428.648		
	14.400	-32[illegible]2.062	0.284	9428.648		

SERIES II CASE 3 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-6.046	-2.036	-0.167	-0.031	-30.664	-40.375
MAXIMUM	14.700	1.528	1.929	0.139	0.049	0.000	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-1.375	-1.711	0.064	0.012	-0.257	-34.400
	1.200	0.362	-1.609	-0.050	0.035	-0.910	-35.422
	1.800	0.227	-1.509	-0.045	-0.020	-0.348	-36.358
	2.400	-3.280	-1.394	0.127	0.009	-1.521	-37.213
	3.000	0.110	-1.113	-0.067	0.043	-2.516	-37.990
	3.600	-0.137	-0.980	-0.063	-0.024	-2.040	-38.613
	4.200	-3.359	-0.818	0.120	-0.006	-3.107	-39.158
	4.800	-1.127	-0.723	-0.018	0.018	-4.878	-39.636
	5.400	0.005	-0.460	-0.096	-0.016	-4.691	-39.952
	6.000	-3.202	-0.262	0.089	-0.017	-5.657	-40.187
	6.600	-2.578	-0.292	0.031	0.048	-7.842	-40.356
	7.200	0.241	0.038	-0.129	-0.004	-8.099	-40.359
	7.800	-3.001	0.275	0.056	-0.025	-9.960	-40.284
	8.400	-3.632	0.136	0.080	0.042	-11.405	-40.141
	9.000	0.149	0.597	-0.145	0.011	-12.256	-39.851
	9.600	-2.816	0.901	0.022	-0.030	-13.014	-39.462
	10.200	-1.765	0.650	0.122	0.031	-15.556	-38.997
	10.800	-0.574	1.125	-0.130	0.027	-17.101	-38.413
	11.400	-2.033	1.315	-0.011	-0.030	-17.814	-37.712
	12.000	0.419	1.253	0.139	0.015	-20.356	-36.931
	12.600	-1.536	1.581	-0.092	0.039	-22.581	-36.062
	13.200	-2.463	1.819	-0.045	-0.027	-23.357	-35.045
	13.800	-3.615	1.875	0.132	0.002	-25.824	-33.960
	14.400	-4.901	-1.771	-0.167	0.010	-29.084	-33.721
	14.700	-6.046	-2.036	-0.036	-0.020	-30.664	-34.491

SERIES II CASE 4

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-4.677	-1.841	-0.144	-0.033	-21.944	-42.291
MAXIMUM	14.700	1.393	1.443	0.139	0.046	0.000	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-1.340	-1.757	0.059	0.010	-0.266	-34.4[illegible]
	1.200	0.279	-1.712	-0.047	0.032	-0.940	-35.481
	1.800	-0.124	-1.651	-0.035	-0.020	-0.418	-36.494
	2.400 *	-3.033	-1.502	0.125	0.013	-1.450	-37.444
	3.000	0.508	-1.280	-0.087	0.037	-2.459	-38.330
	3.600	-0.540	-1.206	-0.048	-0.030	-1.957	-39.084
	4.200	-3.377	-1.105	0.132	-0.003	-3.084	-39.791
	4.800	-0.325	-0.933	-0.040	0.044	-4.614	-40.423
	5.400	0.217	-0.782	-0.081	-0.023	-4.231	-40.917
	6.000	-3.128	-0.622	0.104	-0.016	-5.161	-41.353
	6.600	-1.524	-0.605	0.009	0.046	-7.063	-41.739
	7.200	0.422	-0.359	-0.114	-0.013	-6.950	-41.975
	7.800	-2.729	-0.128	0.072	-0.025	-7.679	-42.148
	8.400	-2.545	-0.265	0.057	0.042	-9.806	-42.277
	9.000	0 .12	0.045	-0.142	0.001	-10.113	-42.263
	9.600	-2.415	0.271	0.039	-0.031	-10.637	-42.176
	10.200	-3.728	0.103	0.105	0.034	-12.840	-42.040
	10.800	0.041	0.505	-0.141	0.016	-13.027	-41.780
	11.400	-2.070	0.701	0.005	-0.033	-14.035	-41.431
	12.000	-4.429	0.576	0.134	0.021	-16.179	-41.024
	12.600	-0.251	0.936	-0.113	0.030	-17.617	-40.531
	13.200	-1.737	1.122	-0.028	-0.032	-17.868	-39.919
	13.800	-4.977	1.115	0.139	0.005	-19.867	-39.247
	14.400	-1.228	1.349	-0.070	0.040	-21.856	-38.515
	14.700	0.045	1.443	-0.144	0.004	-21.944	-38.082

SERIES II CASE 5

	TIME	U A/C	W A/C	THETA DOT
MINIMUM	0.000	-2.058	-1.818	-0.092
MAXIMUM	14.724	1.323	1.920	0.087
1	0.000	0.000	0.000	0.000
3	0.600	-0.365	-1.789	0.038
5	1.200	0.796	-1.818	-0.055
7	1.800	-1.603	-1.777	0.066
9	2.400	0.684	-1.537	-0.071
11	3.000	-2.058	-1.432	0.087
13	3.600	1.230	-1.189	-0.089
15	4.200	-1.990	-1.051	0.084
17	4.800	1.297	-0.813	-0.091
19	5.400	-1.742	-0.696	0.071
21	6.000	1.085	-0.448	-0.080
23	6.600	-1.383	-0.340	0.052
25	7.200	0.562	-0.120	-0.057
27	7.800	-0.989	-0.005	0.031
29	8.400	0.120	0.175	-0.028
31	9.000	-0.594	0.327	0.011
33	9.600	-0.454	0.459	0.002
35	10.199	-0.201	0.659	-0.010
37	10.798	-1.027	0.744	0.033
39	11.398	0.102	0.990	-0.031
41	11.997	-1.564	1.042	0.061
43	12.597	0.587	1.322	-0.052
45	13.197	-1.309	1.397	0.080
47	13.795	0.936	1.656	-0.073
49	14.405	-2.020	1.760	0.087
51	14.724	-0.110	1.920	-0.016

SERIES II CASE 6

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
[illegible]	0.000	-5.1[illegible]	-1.500	-0.143	-0.038	-9.[illegible]	-4[illegible].14[illegible]
[illegible]	14.700	1.[illegible]	0.657	0.139	0.041	0.004	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-0.[illegible]04	-1.206	0.041	0.007	-0.139	-34.430
	1.200	0.112	-1.478	-0.027	0.026	-0.670	-35.544
	1.800	-0.257	-1.330	-0.028	-0.015	-0.225	-36.677
	2.400	-2.[illegible]	-1.495	0.111	0.021	-1.210	-37.779
	3.000	1.574	-1.542	-0.121	0.023	-1.715	-38.819
	3.600	-2.[illegible]	-1.529	-0.020	-0.037	-1.209	-39.762
	4.200	-5.1[illegible]	-1.5[illegible]	0.139	0.005	-2.397	-40.673
	4.800	0.[illegible]	-1.229	-0.031	0.034	-3.361	-41.523
	5.400	0.0[illegible]	-1.197	-0.052	-0.034	-2.671	-42.256
	6.000	-2.[illegible]	-1.107	0.127	-0.009	-3.532	-42.954
	6.600	-0.[illegible]12	-0.963	-0.034	0.040	-4.817	-43.620
	7.200	0.[illegible]	-0.864	-0.035	-0.027	-4.110	-44.141
	7.800	-0.[illegible]	-0.721	0.101	-0.021	-4.623	-44.627
	8.400	-0.[illegible]	-0.702	0.013	0.041	-6.105	-45.089
	9.000	1.[illegible]11	-0.522	-0.117	-0.016	-5.525	-45.401
	9.600	-1.[illegible]	-0.375	0.069	-0.030	-5.684	-45.676
	10.200	-1.[illegible]	-0.436	0.001	0.037	-7.222	-45.928
	10.800	1.[illegible]	-0.149	-0.143	-0.002	-6.915	-46.042
	11.400	-1.195	-0.053	0.036	-0.036	-6.719	-46.106
	12.000	-2.[illegible]	-0.149	0.108	0.028	-8.168	-46.143
	12.600	1.444	0.209	-0.140	0.013	-8.247	-46.075
	13.200	-0.[illegible]	0.300	0.004	-0.038	-7.728	-45.927
	13.800	-2.[illegible]	0.253	0.135	0.016	-8.960	-45.746
	14.400	1.345	0.637	-0.112	0.026	-9.456	-45.494
	14.700	1.501	0.562	-0.122	-0.014	-8.923	-45.316

SERIES II CASE 9

	TIME	U A/C	W A/C	THETA DOT
MINIMUM	0.000	-1.991	-1.898	-0.092
MAXIMUM	-0.000	1.775	0.764	0.087

TIME	U A/C	W A/C	THETA DOT
0.000	0.000	0.000	0.000
0.600	-0.812	-1.823	0.034
1.200	0.732	-1.898	-0.052
1.800	-1.576	-1.897	0.065
2.400	0.947	-1.692	-0.073
3.000	-1.991	-1.612	0.087
3.600	1.344	-1.400	-0.089
4.200	-1.849	-1.290	0.093
4.800	1.464	-1.079	-0.091
5.400	-1.536	-0.984	0.070
6.000	1.316	-0.771	-0.080
6.600	-1.117	-0.698	0.052
7.200	0.965	-0.499	-0.057
7.800	-0.604	-0.421	0.032
8.400	0.500	-0.258	-0.029
8.999	-0.211	-0.147	0.011
9.599	0.001	-0.028	0.001
10.199	0.241	0.126	-0.010
10.797	-0.496	0.221	0.031
11.396	0.893	0.401	-0.030
11.996	-0.967	0.441	0.060
12.596	1.148	0.677	-0.051
12.996	-0.543	0.764	0.042

SERIES II CASE 10

	TIME	U A/C	W A/C	THETA DOT
MINIMUM	0.000	-2.139	-1.886	-0.092
MAXIMUM	14.996	1.487	1.214	0.087

TIME	U A/C	W A/C	THETA DOT
0.000	0.000	0.000	0.000
0.600	-0.936	-1.819	0.036
1.200	0.[illegible]	-1.836	-0.053
1.800	-1.[illegible]4	-1.891	0.0[illegible]4
2.400	0.718	-1.[illegible]	-0.070
3.000	-2.139	-1.595	0.047
3.600	1.180	-1.590	-0.089
4.200	-2.019	-1.272	0.084
4.800	1.309	-1.262	-0.052
5.400	-1.751	-0.962	0.072
6.000	1.104	-0.751	-0.092
6.600	-1.557	-0.672	0.054
7.200	0.606	-0.475	-0.060
7.800	-0.312	-0.304	0.034
8.400	0.322	-0.233	-0.033
9.000	-0.016	-0.119	0.014
9.600	-0.222	-0.003	-0.002
10.199	-0.091	0.155	-0.007
10.799	-0.727	0.225	0.028
11.399	0.334	0.429	-0.028
11.997	-1.234	0.463	0.057
12.597	0.742	0.705	-0.048
13.197	-1.571	0.742	0.074
13.797	1.134	0.932	-0.069
14.397	-1.702	1.057	0.087
14.996	2.265	1.214	-0.018

SERIES II CASE 11

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-1.311	-1.923	-0.095	-0.019	-0.500	-43.210
MAXIMUM	14.724	2.255	1.491	0.087	0.017	8.221	-33.095
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	0.000	-1.587	-0.060	0.006	0.002	-33.102
	1.200	-0.005	-0.299	0.035	-0.000	0.002	-33.749
	1.800	-0.654	-0.790	0.025	-0.001	-0.041	-33.933
	2.400	0.311	0.576	-0.062	0.014	-0.500	-33.790
	3.000	-0.109	-1.779	0.066	0.001	-0.237	-34.379
	3.600	2.0[illegible]	-1.820	-0.095	0.002	-0.071	-35.617
	4.200	-0.078	-1.042	0.070	-0.010	0.343	-36.091
	4.800	1.227	-1.563	-0.080	0.007	0.249	-37.505
	5.400	-0.511	-1.355	0.052	-0.014	0.898	-38.551
	6.000	1.002	-1.149	-0.058	0.011	0.725	-39.119
	6.600	-0.074	-1.119	0.032	-0.017	1.550	-39.307
	7.200	1.173	-0.962	-0.030	0.014	1.313	-40.466
	7.800	0.419	-0.923	0.012	-0.018	2.302	-41.020
	8.400	0.723	-0.738	-0.000	0.015	2.079	-41.548
	[illegible]	[illegible]	-0.099	-0.009	-0.019	3.151	-41.969
	9.599	0.207	-0.615	0.029	0.014	3.003	-42.350
	10.199	1.372	-0.470	-0.028	-0.017	4.099	-42.652
	10.799	-0.178	-0.456	0.058	0.012	4.596	-42.904
	11.399	1.043	-0.250	-0.049	-0.015	5.145	-43.065
	11.999	-0.482	-0.216	0.078	0.007	5.323	-43.175
	12.599	2.543	-0.228	-0.060	-0.011	6.289	-43.207
	13.199	-0.929	0.031	0.046	0.003	6.694	-43.181
	13.799	2.702	0.229	-0.085	-0.007	7.557	-43.094
	14.399	-0.521	0.242	0.036	-0.005	8.197	-42.919
	14.724	1.112	0.379	0.026	0.015	8.221	-42.833

SERIES II CASE 14

	TIME	U A/C	V A/C	THETA DOT	THETA	X(1) A/C	Z(1) A/C
MINIMUM	0.000	-2.246	-1.991	-0.092	-0.018	-2.444	-46.728
MAXIMUM	14.696	1.692	0.502	0.087	0.016	0.000	-33.500
	0.000	0.000	0.000	0.000	0.000	0.000	-33.500
	0.600	-0.390	-1.850	0.032	0.004	-0.160	-34.439
	1.200	0.621	-1.959	-0.051	0.001	-0.309	-35.584
	1.800	-1.637	-1.991	0.064	0.011	-0.728	-36.759
	2.400	0.353	-1.913	-0.072	-0.010	-0.606	-37.871
	3.000	-2.246	-1.744	0.087	0.001	-1.081	-38.926
	3.600	1.241	-1.579	-0.089	-0.005	-1.199	-39.915
	4.200	-1.394	-1.498	0.084	-0.004	-1.420	-40.833
	4.800	1.149	-1.317	-0.092	0.001	-1.099	-41.693
	5.400	-1.077	-1.248	0.072	-0.010	-1.657	-42.472
	6.000	1.530	-1.063	-0.081	0.007	-2.083	-43.202
	6.600	-1.149	-1.017	0.054	-0.014	-1.501	-43.846
	7.200	1.049	-0.843	-0.060	0.011	-2.335	-44.446
	7.800	-0.691	-0.787	0.034	-0.017	1.855	-44.944
	8.399	0.624	-0.655	-0.033	0.014	-2.444	-45.413
	8.999	-0.212	-0.590	0.014	-0.018	-1.821	-45.780
	9.599	0.150	-0.491	-0.003	0.016	-2.406	-46.121
	10.198	0.257	-0.364	-0.006	-0.018	-1.699	-46.355
	10.798	-0.306	-0.327	0.027	0.015	-2.218	-46.560
	11.397	0.725	-0.147	-0.027	-0.017	-1.487	-46.661
	11.997	-0.760	-0.123	0.056	0.012	-1.882	-46.728
	12.597	1.130	0.072	-0.047	-0.015	-1.188	-46.701
	13.197	-1.062	0.090	0.077	0.008	-1.401	-46.625
	13.796	1.675	0.293	-0.067	-0.011	-0.801	-46.470
	14.396	-1.152	0.343	0.087	0.002	-0.789	-46.252
	14.696	0.133	0.502	-0.021	0.015	-0.879	-46.135

SERIES II CASE 15

	TIME	U A/C	W A/C	THETA DOT
MINIMUM	0.000	-1.937	-1.973	-0.092
MAXIMUM	14.724	1.751	0.530	0.087

TIME	U A/C	W A/C	THETA DOT
0.000	0.000	0.000	0.000
0.600	-0.810	-1.842	0.034
1.200	0.735	-1.946	-0.052
1.800	-1.549	-1.973	0.064
2.400	0.902	-1.793	-0.070
3.000	-1.987	-1.747	0.087
3.600	1.309	-1.562	-0.088
4.200	-1.692	-1.432	0.084
4.800	1.462	-1.300	-0.092
5.400	-1.603	-1.229	0.073
6.000	1.350	-1.045	-0.082
6.600	-1.211	-0.907	0.055
7.200	1.020	-0.822	-0.062
7.800	-0.774	-0.776	0.035
8.400	0.579	-0.633	-0.035
9.000	-0.336	-0.558	0.015
9.599	0.085	-0.459	-0.005
10.198	0.101	-0.341	-0.005
10.798	-0.411	-0.280	0.024
11.397	0.540	-0.124	-0.025
11.997	-0.900	-0.109	0.054
12.597	0.980	0.094	-0.045
13.196	-1.247	0.107	0.075
13.805	1.368	0.317	-0.063
14.405	-1.366	0.355	0.085
14.724	0.753	0.530	-0.028

SERIES II CASE 16

SERIES III

CASE	THRUST	SWH	θ_t	δ	μ	T_B	
1	33650	30	-.022	94°	.68	0	
2	33650	10	-.0205	4°	.15	5	
3	33600	30	-.013	4°	.68	5	(1)
4	33650	30	-.019	4°	.68	5	
5	33750	30	-.017	4°	.68	5	
6	33700	30	-.021	94	.68	5	
7	33800	30	-.0205	64	.68	3	
8	33800	30	-.0205	64	.68	5	(1)
9	33800	30	-.014	64	.68	0	
10	338500	30	-.0192	49	.68	5	
11	33850	30	-.0232	94	.3	5	(2)

1. 20 KT. HEADWIND
2. DROP HEIGHT = 16"   FOR ALL OTHER CASES
   DROP HEIGHT = 7.5"

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-0.004	-4.902	-0.112	-0.016	-1.189	-76.615
MAXIMUM	14.700	5.154	2.258	0.231	0.157	30.331	-33.300
	0.000	0.000	-3.153	-0.001	0.071	0.000	-33.500
	0.600	-0.004	-1.643	0.032	0.157	0.021	-33.300
	1.200	-0.004	-3.713	-0.029	0.133	-0.352	-35.777
	1.800	-0.004	-2.905	0.015	0.136	-0.597	-37.605
	2.400	-0.001	-3.331	-0.041	0.123	-0.873	-39.627
	3.000	0.002	-2.731	0.007	0.108	-1.125	-41.708
	3.600	[illegible]	-3.130	-0.047	0.116	-1.129	-43.220
	4.200	2.994	-3.763	-0.079	0.076	-0.361	-45.451
	4.800	0.154	-4.604	-0.102	0.016	2.217	-48.070
	5.400	1.731	-4.435	0.065	0.008	4.188	-50.803
	6.000	4.001	-4.227	-0.095	0.002	6.020	-53.422
	6.600	1.504	-4.053	0.077	-0.005	7.851	-55.906
	7.200	1.110	-3.727	-0.086	0.003	9.318	-58.273
	7.800	1.038	-3.619	0.060	-0.010	11.347	-60.497
	8.400	4.124	-3.264	-0.067	0.013	12.624	-62.509
	9.000	2.077	-3.190	0.039	-0.013	14.814	-64.561
	9.600	[illegible]	-2.844	-0.059	0.017	15.957	-66.411
	10.200	2.954	-2.757	0.018	-0.015	18.248	-68.095
	10.800	3.016	-2.448	-0.008	0.018	19.319	-69.679
	11.400	2.401	-2.320	-0.004	-0.016	21.648	-71.098
	12.000	2.416	-2.058	0.023	0.018	22.715	-72.416
	12.600	3.240	-1.377	-0.025	-0.015	25.010	-73.566
	13.200	1.917	-1.608	0.054	0.015	26.138	-74.611
	13.800	3.033	-1.427	-0.046	-0.012	28.335	-75.503
	14.400	1.375	-1.239	0.076	0.011	29.584	-76.276
	14.700	3.737	-0.942	-0.050	0.015	30.331	-76.615

SERIES III CASE 1

	TIME	NOSE GEAR	MAIN GEAR	,ZLG	NGL	NGL
MINIMUM	0.000	0.000	0.000	-53059.102	1.755	3.463
MAXIMUM	14.700	8329.104	44270.937	0.000	12.000	12.000
	0.000	5463.333	0.000	-5463.833	12.000	7.560
	0.600	8312.777	38186.325	-46499.102	1.755	3.463
	1.200	6448.421	11186.449	-17634.871	7.205	5.748
	1.800	5534.751	11353.262	-16887.992	7.368	7.015
	2.400	4579.261	7695.782	-12275.043	9.721	9.237
	3.000	3979.434	0.000	-3979.434	12.000	11.268
	3.600	0.000	7227.313	-7227.313	11.799	12.000
	4.200	0.000	0.000	0.000	12.000	12.000
	4.800	0.000	0.000	0.000	12.000	12.000
	5.400	0.000	0.000	0.000	12.000	12.000
	6.000	0.000	0.000	0.000	12.000	12.000
	6.600	0.000	0.000	0.000	12.000	12.000
	7.200	0.000	0.000	0.000	12.000	12.000
	7.800	0.000	0.000	0.000	12.000	12.000
	8.400	0.000	0.000	0.000	12.000	12.000
	9.000	0.000	0.000	0.000	12.000	12.000
	9.600	0.000	0.000	0.000	12.000	12.000
	10.200	0.000	0.000	0.000	12.000	12.000
	10.800	0.000	0.000	0.000	12.000	12.000
	11.400	0.000	0.000	0.000	12.000	12.000
	12.000	0.000	0.000	0.000	12.000	12.000
	12.600	0.000	0.000	0.000	12.000	12.000
	13.200	0.000	0.000	0.000	12.000	12.000
	13.800	0.000	0.000	0.000	12.000	12.000
	14.400	0.000	0.000	0.000	12.000	12.000
	14.700	0.000	0.000	0.000	12.000	12.000

SERIES III CASE 1 (Cont'd)

	TIME	Z(I) S CG	Z-FWD CP	Z-REAR CP	ZF	BIS	GAMMA
MINIMUM	0.000	-18.296	-44.785	-44.769	-33649.633	-0.192	-1.417
MAXIMUM	14.700	0.000	-27.913	-26.000	0.000	0.284	1.154
	0.000	0.000	-27.913	-26.000	0.000	0.000	-1.264
	0.600	-1.959	-29.735	-27.896	-6052.793	0.284	-1.024
	1.200	-3.767	-31.590	-29.751	-11891.156	0.284	-1.308
	1.800	-5.585	-33.361	-31.581	-17308.035	0.284	-1.239
	2.400	-7.594	-35.053	-33.355	-22112.199	0.284	-1.319
	3.000	-9.244	-36.557	-35.060	-26133.023	0.284	-1.272
	3.600	-10.653	-38.168	-36.690	-29227.914	0.284	-1.353
	4.200	-12.119	-39.593	-38.248	-31287.344	0.284	-0.900
	4.800	-13.469	-40.900	-39.753	-33590.336	-0.107	-0.729
	5.400	-14.675	-42.100	-41.064	-33607.148	-0.050	-1.200
	6.000	-15.725	-43.055	-42.191	-33612.086	-0.047	-0.737
	6.600	-16.527	-43.808	-43.126	-33405.211	-0.121	-1.240
	7.200	-17.312	-44.346	-43.852	-33434.469	0.113	-0.694
	7.800	-17.952	-44.573	-44.379	-33135.320	-0.175	-1.132
	8.400	-18.101	-44.735	-44.682	-32373.523	0.215	-0.669
	9.000	-18.235	-44.674	-44.769	-33031.664	-0.192	-0.994
	9.600	-18.256	-44.318	-44.640	-32407.273	0.273	-0.668
	10.200	-17.942	-43.794	-44.281	-33031.664	-0.192	-0.841
	10.800	-17.535	-43.054	-43.730	-32302.062	0.284	-0.682
	11.400	-16.921	-42.085	-42.940	-33031.664	-0.192	-0.693
	12.000	-16.095 1	-40.962 4	-41.992	-32302.062	0.284	-0.706
	12.600	-15.100	-39.620	-40.811	-33031.664	-0.192	-0.525
	13.200	-13.952	-38.170	-39.510	-32510.695	0.261	-0.743
	13.800	-12.606	-36.525	-37.999	-33031.654	-0.192	-0.374
	14.400	-11.225	-34.808	-36.401	-33233.320	0.158	-0.734
	14.700	-10.463	-33.904	-35.550	-32543.742	0.257	-0.247

SERIES III CASE 1 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-2.460	-2.017	-0.094	-0.017	-6.962	-38.936
MAXIMUM	9.800	0.108	1.555	0.087	0.021	0.006	-33.064
	0.000	0.000	-0.232	0.001	-0.002	0.000	-33.500
	0.400	0.000	0.454	0.010	0.010	0.002	-33.064
	0.800	0.000	-1.215	-0.019	-0.008	0.002	-33.591
	1.200	0.000	0.762	0.071	0.005	0.003	-33.655
	1.600	0.000	-0.319	-0.020	0.021	0.006	-33.419
	2.000	0.000	-1.714	-0.034	-0.000	0.001	-33.932
	2.400	-0.000	-0.40	0.035	0.003	0.001	-34.331
	2.800	-0.134	-0.260	0.019	0.008	-0.044	-34.353
	3.200	-0.135	-1.22	-0.024	0.001	-0.099	-34.602
	3.600	-1.075	0.310	0.035	0.013	-0.505	-34.741
	4.000	-0.101	-1.043	-0.061	0.009	-0.815	-34.555
	4.400	-1.134	-1.805	0.019	-0.002	-0.993	-35.299
	4.800	-1.492	-1.6	0.031	0.018	-1.711	-35.977
	5.200	0.804	-1.397	-0.094	-0.001	-1.732	-36.564
	5.600	-1.400	-1.222	0.024	-0.016	-1.836	-37.094
	6.000	-2.205	-1.106	0.069	0.011	-2.718	-37.571
	6.400	0.765	-0.840	-0.038	0.005	-2.967	-37.956
	6.800	-0.806	-0.719	0.003	-0.017	-2.919	-38.289
	7.200	-2.403	-0.662	0.084	0.006	-3.721	-38.557
	7.600	0.467	-0.326	-0.071	0.010	-4.142	-38.759
	8.000	-0.507	-0.219	-0.019	-0.017	-3.980	-38.876
	8.400	-2.460	-0.106	0.097	-0.000	-4.621	-38.936
	8.800	-0.008	0.152	-0.044	0.015	-5.236	-38.945
	9.200	-0.255	0.232	-0.041	-0.015	-5.017	-38.854
	9.600	-2.238	0.443	0.078	-0.006	-5.493	-38.726
	9.800	-2.150	0.410	0.072	0.010	-5.962	-38.620

SERIES III CASE 2

	TIME	Y A/C	Φ A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-6.514	-0.275	-0.162	-0.151	-91.086
MAXIMUM	14.699	22.179	-1.407	0.258	0.101	147.844	-33.500
	0.000	0.000	-3.153	0.012	-0.006	0.000	-33.500
	0.600	0.001	-4.708	-0.056	0.007	-0.010	-34.963
	1.200	0.000	-1.972	0.079	0.019	-0.019	-36.956
	1.800	0.000	-3.801	-0.025	0.044	-0.079	-38.471
	2.400	0.073	-3.676	-0.012	0.029	-0.151	-40.852
	3.000	2.224	-1.407	0.035	0.060	0.475	-42.254
	3.600	2.575	-3.764	-0.040	0.062	1.719	-44.011
	4.200	6.131	-3.950	-0.038	0.033	4.254	-46.329
	4.800	10.050	-4.778	-0.105	-0.013	9.169	-49.948
	5.400	10.164	-5.605	-0.058	-0.061	15.643	-51.939
	6.000	[illegible]	-5.125	0.146	-0.026	21.145	-54.925
	6.600	8.805	-4.255	0.090	0.068	25.680	-57.871
	7.200	12.400	-3.330	-0.179	0.039	32.013	-60.608
	7.800	12.449	-5.055	-0.183	-0.096	40.229	-63.315
	8.400	11.577	-5.179	0.004	-0.148	47.801	-65.951
	9.000	10.457	-5.404	0.191	-0.088	54.769	-68.634
	9.600	11.219	-3.822	0.202	0.054	60.990	-71.313
	10.200	15.091	-2.748	-0.069	0.092	68.786	-73.868
	10.800	17.034	-4.354	-0.275	-0.025	78.814	-76.257
	11.400	[illegible]	-6.256	-0.109	-0.144	89.208	-78.599
	12.000	15.153	-6.342	0.078	-0.152	98.966	-80.966
	12.600	14.206	-4.692	0.256	-0.048	108.136	-83.362
	13.200	16.029	-2.591	0.121	0.086	117.166	-85.744
	13.800	20.404	-2.044	-0.150	0.075	128.259	-87.968
	14.399	21.783	-4.544	-0.245	-0.070	141.360	-90.051
	14.699	22.004	-5.154	-0.152	-0.129	147.844	-91.065

SERIES III CASE 3

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-4.640	-0.093	-0.019	-0.150	-77.885
MAXIMUM	14.700	10.995	-1.013	0.097	0.071	99.454	-33.500
	0.000	0.000	-3.153	0.012	-0.006	0.000	-33.500
	0.600	0.000	-4.493	-0.051	0.007	-0.008	-34.945
	1.200	0.000	-2.121	0.066	0.017	-0.017	-36.986
	1.800	0.000	-3.022	-0.004	0.041	-0.070	-38.527
	2.400	0.007	-3.838	-0.012	0.033	-0.150	-40.702
	3.000	1.452	-1.881	0.080	0.060	0.312	-42.219
	3.600	2.852	-3.295	-0.011	0.064	1.409	-43.996
	4.200	6.271	-3.278	-0.036	0.048	4.010	-46.023
	4.800	10.247	-4.202	-0.081	0.015	8.870	-48.420
	5.400	7.757	-4.495	0.056	0.001	14.432	-51.167
	6.000	10.545	-4.216	-0.093	0.005	19.630	-53.821
	6.600	7.010	-4.204	0.062	-0.012	25.215	-56.344
	7.200	10.238	-3.729	-0.070	0.009	30.129	-58.764
	7.800	9.103	-3.810	0.043	-0.016	35.945	-61.023
	8.400	9.992	-3.290	-0.044	0.013	40.798	-63.189
	9.000	8.810	-3.407	0.022	-0.019	46.801	-65.189
	9.600	9.445	-2.833	-0.015	0.015	51.650	-67.035
	10.200	9.113	-2.990	0.001	-0.019	57.780	-68.834
	10.800	8.378	-2.506	0.016	0.015	62.683	-70.481
	11.400	9.630	-2.557	-0.020	-0.018	68.875	-71.962
	12.000	8.491	-2.141	0.047	0.013	73.895	-73.348
	12.600	10.145	-2.107	-0.042	-0.016	80.063	-74.568
	13.200	8.117	-1.759	0.072	0.009	85.264	-75.685
	13.800	10.301	-1.659	-0.063	-0.012	91.361	-76.655
	14.400	7.269	-1.543	0.095	0.003	96.704	-77.500
	14.700	10.295	-1.013	-0.026	0.015	99.454	-77.885

SERIES III CASE 4

	TIME	•ZF	XF	NOSE GEAR	MAIN GEAR	•ZLG
MINIMUM	0.000	-33655.649	-6421.178	0.000	0.000	-35774.117
MAXIMUM	14.700	0.000	9428.648	9636.971	27134.145	0.000

0.000	0.000	0.000	5483.865	12424.002	-17907.867
0.600	-6172.213	1233.938	8441.678	21721.105	-30162.785
1.200	-11591.146	3470.927	6197.318	13116.193	-19313.512
1.800	-17803.012	5052.109	5675.984	13102.955	-18779.940
2.400	-22111.780	6454.229	4686.859	6148.578	-10835.437
3.000	-26152.062	7527.858	4017.472	8005.454	-12022.926
3.600	-28227.049	8051.008	3859.220	0.000	-3859.220
4.200	-31217.197	8132.416	4072.364	0.000	-4072.364
4.800	-32[illegible].059	4385.530	3853.756	0.000	-3853.756
5.400	-33411.414	-3909.958	0.000	0.000	0.000
6.000	-33551.593	2544.000	0.000	0.000	0.000
6.600	-33171.492	-5654.569	0.000	0.000	0.000
7.200	-32964.023	6759.391	0.000	0.000	0.000
7.800	-33033.727	-6410.563	0.000	0.000	0.000
8.400	-32451.016	8310.277	0.000	0.000	0.000
9.000	-33031.064	-6421.178	0.000	0.000	0.000
9.600	-32502.062	9428.648	0.000	0.000	0.000
10.200	-33031.064	-6421.178	0.000	0.000	0.000
10.800	-32502.062	9428.648	0.000	0.000	0.000
11.400	-33031.064	-6421.178	0.000	0.000	0.000
12.000	-32524.935	9335.965	0.000	0.000	0.000
12.600	-33031.064	-6421.178	0.000	0.000	0.000
13.200	-33034.309	6233.828	0.000	0.000	0.000
13.800	-33031.064	-6121.178	0.000	0.000	0.000
14.400	-33069.306	2322.324	0.000	0.000	0.000
14.700	-32518.672	9371.541	0.000	0.000	0.000

SERIES III CASE 4 (Cont'd)

	TIME	Z(I) S CG	Z-FWD CP	Z-REAR CP	HGL	NGL
MINIMUM	0.000	-18.296	-49.956	-48.050	2.951	3.414
MAXIMUM	14.700	0.000	-26.389	-26.539	12.000	12.000
	0.000	0.000	-26.389	-26.539	6.616	7.560
	0.600	-1.889	-28.424	-28.376	2.951	3.414
	1.200	-3.767	-30.438	-30.193	6.504	6.153
	1.800	-5.595	-32.409	-31.969	5.705	6.721
	2.400	-7.354	-34.316	-33.636	11.488	8.981
	3.000	-9.044	-36.154	-35.341	11.542	11.051
	3.600	-10.[illegible]43	-37.919	-36.931	12.000	11.851
	4.200	-12.118	-39.640	-38.487	12.000	11.661
	4.800	-13.468	-41.389	-40.054	12.000	11.825
	5.400	-14.676	-43.009	-41.567	12.000	12.000
	6.000	-15.725	-44.516	-42.950	12.000	12.000
	6.600	-16.627	-45.898	-44.226	12.000	12.000
	7.200	-17.312	-47.069	-45.309	12.000	12.000
	7.800	-17.832	-48.109	-46.281	12.000	12.
	8.400	-18.151	-48.878	-47.000		
	9.000	-18.296	-49.503	-47.595		
	9.600	-18.236	-49.809	-47.892		
	10.200	-17.942	-49.956	-48.050		
	10.800	-17.535	-49.758	-47.884		
	11.400	-16.901	-49.394	-47.561		
	12.000	-16.080	-48.661	-46.909		
	12.600	-15.100	-47.742	-46.080		
	13.200	-13.933	-46.496	-44.941		
	13.800	-12.656	-45.039	-43.609		
	14.400	-11.225	-43.293	-42.002		
	14.700	-10.463	-42.328	-41.112		

SERIES III CASE 4 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-7.624	-0.274	-0.159	-0.152	-96.612
MAXIMUM	14.999	24.040	-1.453	0.259	0.103	164.918	-33.500
	0.000	0.000	-5.153	0.012	-0.006	0.000	-33.500
	0.600	0.000	-4.727	-0.055	0.007	-0.010	-34.963
	1.200	0.000	-1.948	0.090	0.020	-0.019	-36.955
	1.800	0.000	-3.835	-0.226	0.044	-0.080	-38.465
	2.400	0.533	-3.690	-0.013	0.028	-0.152	-40.857
	3.000	1.704	-1.934	0.267	0.062	0.423	-42.207
	3.600	2.321	-3.251	-0.009	0.060	1.515	-44.043
	4.200	6.303	-5.533	-0.012	0.047	4.229	-46.066
	4.800	10.313	-4.129	-0.096	0.015	9.215	-48.442
	5.400	13.125	-5.728	-0.105	-0.045	16.576	-51.360
	6.000	11.048	-5.372	0.254	-0.064	24.107	-54.456
	6.600	9.596	-4.972	0.189	0.020	30.185	-57.541
	7.200	12.832	-5.935	-0.028	0.078	36.559	-60.606
	7.800	15.121	-5.335	-0.252	-0.017	45.290	-63.510
	8.400	14.121	-6.735	-0.103	-0.132	54.677	-66.388
	9.000	13.124	-6.773	0.085	-0.135	63.309	-69.318
	9.600	12.116	-5.346	0.256	-0.028	71.179	-72.306
	10.200	15.237	-3.496	0.085	0.092	79.091	-75.296
	10.800	18.470	-3.547	-0.135	0.060	89.132	-78.161
	11.400	19.034	-6.349	-0.214	-0.089	100.990	-80.935
	11.999	17.424	-7.624	-0.027	-0.159	112.286	-83.747
	12.599	15.822	-6.831	0.161	-0.118	123.091	-86.633
	13.199	16.672	-4.541	0.259	0.025	133.128	-89.575
	13.799	20.842	-2.514	-0.000	0.103	144.212	-92.474
	14.399	24.040	-4.032	-0.256	0.021	157.515	-95.248
	14.999	22.890	-6.027	-0.256	-0.061	164.318	-96.612

SERIES III CASE 5

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	-0.219	-6.247	-0.275	-0.154	-1.254	-94.698
MAXIMUM	14.6[illegible]	15.522	3.775	0.304	0.160	81.119	-33.244

TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
0.000	0.000	-3.153	-0.001	0.071	0.000	-33.500
0.600	-0.010	-2.223	0.065	0.160	0.017	-33.244
1.200	-0.010	-3.430	-0.020	0.130	-0.373	-35.829
1.800	-0.019	-2.406	0.022	0.140	-0.611	-37.524
2.400	[illegible]	-4.0[illegible]	-0.050	0.129	-0.912	-39.609
3.000	[illegible]	[illegible]	0.000	0.107	-1.178	-41.823
3.600	[illegible]	[illegible]	-0.026	0.113	-1.194	-43.207
4.200	[illegible]	-4.0[illegible]	-0.063	0.072	-0.544	-45.501
4.800	[illegible]	-4.541	-0.116	0.009	2.042	-48.200
5.400	[illegible]	-5.425	-0.077	-0.070	5.909	-51.199
6.000	[illegible]	-5.201	0.109	-0.059	8.709	-54.203
6.600	2.357	-4.918	0.188	0.048	10.160	-57.200
7.200	[illegible]	-1.294	-0.072	0.084	12.541	-60.147
7.800	4.751	-4.916	-0.256	-0.032	17.178	-62.946
8.400	[illegible]	-5.600	-0.081	-0.134	21.940	-65.732
9.000	[illegible]	-5.511	0.100	-0.125	25.554	-68.567
9.600	4.108	-4.560	0.263	-0.007	29.112	-71.449
10.200	7.770	-3.701	0.061	0.103	32.481	-74.322
10.800	11.02[illegible]	[illegible]	-0.208	0.056	37.973	-77.070
11.400	10.771	-5.479	-0.199	-0.093	45.026	-79.740
12.000	9.273	-6.247	-0.012	-0.154	151.356	-83.440
12.600	[illegible]	-5.062	0.175	-0.103	57.133	-85.204
13.1[illegible]	[illegible]	-4.594	0.246	0.143	62.076	-88.012
13.7[illegible]	12.5[illegible]	-5.150	-0.021	0.109	68.193	-90.762
14.3[illegible]	13.922	-4.071	-0.267	0.015	70.453	-93.391
14.6[illegible]	14.403	-5.322	-0.241	-0.066	81.119	-94.698

SERIES III CASE 6

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
[illegible]	0.000	0.000	[illegible]	-0.033	-0.016	-0.042	-55.993
[illegible]	[illegible]	[illegible]	-1.445	0.084	0.044	35.341	-33.500
	0.000	0.000	-3.153	0.012	-0.006	0.000	-33.500
	0.200	0.000	-1.440	0.057	0.003	0.001	-33.9[illegible]
	0.400	0.000	-3.3[illegible]	-0.009	0.012	-0.004	-34.4[illegible]
	[illegible]	0.000	-4.473	-0.023	0.00[illegible]	-0.012	[illegible]
	[illegible]	0.000	-3.[illegible]	0.020	0.003	-0.014	-35.181
	[illegible]	[illegible]	-5.139	0.055	0.011	-0.019	-37.290
	[illegible]	[illegible]	[illegible]	0.018	0.017	-0.029	-33.026
	[illegible]	[illegible]	-3.[illegible]	-0.001	0.019	-0.042	-38.840
	[illegible]	[illegible]	-3.2[illegible]	0.073	0.022	0.066	-39.650
	[illegible]	[illegible]	-2.5[illegible]	0.032	0.031	0.511	-40.341
	[illegible]	[illegible]	-2.574	0.034	0.036	1.329	-40.966
	[illegible]	[illegible]	-2.[illegible]72	0.008	0.042	2.520	-41.639
	[illegible]	[illegible]	-2.939	-0.023	0.044	4.095	-42.404
	[illegible]	[illegible]	-3.4[illegible]	-0.035	0.040	6.262	-43.276
	[illegible]	[illegible]	-4.101	-0.041	0.030	8.437	-44.261
	[illegible]	[illegible]	-4.021	-0.064	0.015	11.196	-45.356
	[illegible]	[illegible]	-4.[illegible]	-0.057	-0.002	14.139	-46.515
	[illegible]	[illegible]	-4.490	0.018	-0.007	16.333	-47.[illegible]
	[illegible]	[illegible]	-4.725	0.073	0.005	19.201	-48.310
	[illegible]	[illegible]	-4.552	0.016	0.019	21.543	-49.957
	[illegible]	[illegible]	-4.[illegible]	-0.085	0.009	24.302	-51.074
	[illegible]	[illegible]	-4.737	-0.001	-0.011	27.275	-52.181
	[illegible]	[illegible]	-4.734	0.014	-0.016	29.903	-53.290
	[illegible]	[illegible]	-4.075	0.081	-0.004	32.540	-54.369
	[illegible]	[illegible]	-4.404	0.050	0.014	34.090	-55.461
	[illegible]	[illegible]	-1.202	-0.004	0.017	35.341	-55.[illegible]99

SERIES III CASE 7

	TIME	NOSE GEAR	MAIN GEAR	MLG
MINIMUM	0.000	0.000	0.000	0.000
MAXIMUM	0.960	8320.041	30161.492	0.000
	0.000	5493.865	12424.002	0.000
	0.240	8320.041	22818.363	0.000
	0.480	7933.811	30161.492	0.000
	0.720	6494.503	11925.191	0.000
	0.960	4876.802	9145.160	0.000
	1.200	4631.723	8653.164	0.000
	1.440	4568.934	7993.093	0.000
	1.680	4297.183	6227.142	0.000
	1.920	3958.917	0.000	0.000
	2.160	0.000	0.000	0.000
	2.400	4023.726	0.000	0.000
	2.640	4215.595	0.000	0.000
	2.880	4747.577	0.000	0.000
	3.120	0.000	0.000	0.000
	3.360	0.000	0.000	0.000
	3.600	0.000	0.000	0.000
	3.840	0.000	0.000	0.000
	4.080	0.000	0.000	0.000
	4.320	0.000	0.000	0.000
	4.560	0.000	0.000	0.000
	4.800	0.000	0.000	0.000
	5.040	0.000	0.000	0.000
	5.280	0.000	0.000	0.000
	5.520	0.000	0.000	0.000
	5.760	0.000	0.000	0.000
	5.980	0.000	0.000	0.000

SERIES III CASE 7 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	[illegible]	-8.467	-0.108	-0.016	0.000	-131.657
MAXIMUM	[illegible]	[illegible]	-1.426	0.087	0.070	605.030	-33.500
	0.000	[illegible]	-3.153	0.012	-0.006	0.000	-33.500
	0.600	[illegible]	-4.056	-0.035	0.011	20.270	-34.953
	1.200	[illegible]	-2.561	0.057	0.015	40.534	-37.342
	[illegible]	[illegible]	-5.243	0.017	0.042	60.754	-39.583
	2.400	[illegible]	-3.434	-0.014	0.041	80.925	-42.635
	3.000	[illegible]	-2.525	0.019	0.065	101.[illegible]	-45.222
	[illegible]	[illegible]	-2.351	0.009	0.065	121.659	-48.394
	[illegible]	[illegible]	-2.915	0.011	0.070	143.993	-51.553
	[illegible]	[illegible]	-4.344	-0.039	0.058	168.305	-55.240
	[illegible]	[illegible]	-7.229	-0.108	0.014	194.352	[illegible]
	6.000	[illegible]	-7.905	0.063	-0.003	221.394	-64.399
	[illegible]	[illegible]	-7.410	-0.045	0.008	247.375	-69.121
	[illegible]	[illegible]	-3.275	0.059	-0.010	273.973	-73.[illegible]
	[illegible]	[illegible]	-7.206	-0.067	P.012	299.857	-78.529
	[illegible]	[illegible]	-8.361	0.043	-0.013	326.641	-83.200
	[illegible]	[illegible]	-7.052	-0.046	0.015	352.437	-87.986
	[illegible]	[illegible]	-8.410	0.026	-0.015	379.374	-92.535
	[illegible]	[illegible]	-5.955	-0.023	0.017	405.173	-97.204
	[illegible]	[illegible]	[illegible]	[illegible]	-0.016	432.266	-101.822
	[illegible]	[illegible]	-6.358	0.001	0.017	458.122	-106.463
	[illegible]	44.220	-8.592	-0.008	-0.016	485.273	-111.056
	[illegible]	[illegible]	-6.954	0.025	0.017	511.202	-115.678
	[illegible]	44.659	-8.321	-0.025	-0.015	538.444	-120.243
	[illegible]	[illegible]	[illegible]	0.049	0.015	564.519	-124.837
	[illegible]	45.127	[illegible]	-0.042	-0.014	591.752	-129.387
	[illegible]	43.57[illegible]	-8.03[illegible]	0.054	-0.012	605.030	-131.657

SERIES III CASE 8

	TIME	NOSE GEAR	MAIN GEAR
MINIMUM	0.000	0.000	0.000
MAXIMUM	14.696	9137.339	29173.963
	0.000	5493.955	12424.002
	0.600	7474.730	23595.048
	1.200	6531.976	13637.549
	1.800	5725.016	12706.340
	2.400	4351.481	7304.053
	3.000	7407.095	10726.025
	3.600	0.000	0.000
	4.200	5711.628	0.000
	4.800	4140.972	0.000
	5.400	0.000	0.000
	6.000	0.000	0.000
	6.600	0.000	0.000
	7.200	0.000	0.000
	7.800	0.000	0.000
	8.400	0.000	0.000
	8.999	0.000	0.000
	9.599	0.000	0.000
	10.199	0.000	0.000
	10.798	0.000	0.000
	11.398	0.000	0.000
	11.997	0.000	0.000
	12.597	0.000	0.000
	13.197	0.000	0.000
	13.797	0.000	0.000
	14.396	0.000	0.000
	14.695	0.000	0.000

SERIES III CASE 8 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-4.713	-0.096	-0.019	-0.150	-87.383
MAXIMUM	14.725	10.923	-1.520	0.097	0.072	97.523	-33.500
	0.000	0.000	-3.153	0.012	-0.006	0.000	-33.500
	0.600	0.000	-4.476	-0.051	0.007	-0.008	-34.941
	1.200	0.000	-2.135	0.065	0.016	-0.017	-36.993
	1.800	0.000	-3.603	-0.003	0.041	-0.069	-38.531
	2.400	0.007	-3.659	-0.012	0.033	-0.150	-40.782
	3.000	2.047	-1.548	0.094	0.059	0.361	-42.257
	3.600	[illegible]	-3.277	-0.010	0.065	1.580	-43.909
	4.200	6.302	-3.409	-0.036	0.047	4.314	-45.059
	4.800	[illegible]	-4.544	-0.071	0.011	9.304	-48.530
	5.400	7.250	-4.613	0.065	0.003	14.568	-51.333
	6.000	[illegible]	-4.508	-0.096	-0.000	19.693	-54.084
	6.600	[illegible]	-4.520	0.075	-0.009	24.948	-56.771
	7.200	10.107	-4.226	-0.084	0.005	29.820	-59.416
	7.800	[illegible]	-4.350	0.059	-0.013	35.336	-61.985
	8.400	10.009	-3.981	-0.066	0.010	40.122	-64.520
	[illegible]	[illegible]	-4.181	0.040	-0.016	45.872	-66.968
	[illegible]	[illegible]	-3.776	-0.041	0.013	50.621	-69.379
	[illegible]	[illegible]	-4.004	0.020	-0.018	56.551	-71.705
	[illegible]	9.300	-3.606	-0.013	0.015	61.319	-74.005
	[illegible]	[illegible]	-3.817	0.001	-0.019	67.372	-76.206
	[illegible]	[illegible]	-3.452	0.015	0.015	72.203	-78.386
	[illegible]	9.496	-3.613	-0.019	-0.018	78.335	-80.469
	[illegible]	[illegible]	-3.515	0.044	0.013	83.307	-82.526
	[illegible]	10.223	-3.406	-0.038	-0.017	89.452	-84.490
	[illegible]	8.159	-3.166	0.068	0.010	94.007	-86.415
	14.725	[illegible]	-2.317	-0.015	0.010	97.523	-87.383

SERIES III CASE 9

	TIME	NOSE GEAR	MAIN GEAR
MINIMUM	0.000	0.000	0.000
MAXIMUM	14.725	8631.131	27054.328
	0.000	5483.865	12424.002
	0.600	8442.986	21974.719
	1.200	6196.542	13009.465
	1.800	5641.619	15019.598
	2.400	4859.759	6080.746
	3.000	5996.155	8025.718
	3.600	5735.062	0.000
	4.200	4028.905	0.000
	4.800	0.000	0.000
	5.400	0.000	0.000
	6.000	0.000	0.000
	6.600	0.000	0.000
	7.200	0.000	0.000
	7.800	0.000	0.000
	8.400	0.000	0.000
	8.999	0.000	0.000
	9.598	0.000	0.000
	10.198	0.000	0.000
	10.798	0.000	0.000
	11.397	0.000	0.000
	11.997	0.000	0.000
	12.596	0.000	0.000
	13.196	0.000	0.000
	13.796	0.000	0.000
	14.395	0.000	0.000
	14.725	0.000	0.000

SERIES III CASE 9 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-4.698	-0.096	-0.018	-0.145	-87.266
MAXIMUM	14.697	10.841	-1.529	0.087	0.071	97.365	-33.500
	0.000	0.000	-3.153	0.012	-0.006	0.000	-33.500
	0.600	0.000	-4.479	-0.051	0.007	-0.008	-34.944
	1.200	0.000	-2.127	0.066	0.017	-0.017	-36.989
	1.800	0.000	-3.518	-0.004	0.041	-0.070	-38.530
	2.400	0.020	-3.552	-0.012	0.032	-0.145	-40.785
	3.000	1.325	-1.579	0.079	0.060	0.351	-42.251
	3.600	5.011	-3.230	-0.007	0.064	1.513	-44.003
	4.200	6.473	-3.333	-0.036	0.048	4.234	-46.027
	4.800	10.061	-4.321	-0.095	0.013	9.195	-48.491
	5.400	7.353	-4.600	0.063	0.003	14.534	-51.263
	6.000	10.335	-4.495	-0.096	0.001	19.689	-54.012
	6.600	7.164	-4.516	0.073	-0.009	24.998	-56.701
	7.200	10.213	-4.213	-0.093	0.006	29.883	-59.349
	7.800	7.534	-4.346	0.057	-0.013	35.438	-61.917
	8.400	9.297	-3.972	-0.064	0.011	40.229	-64.451
	9.000	8.004	-4.177	0.038	-0.016	46.002	-66.893
	9.600	9.615	-3.773	-0.038	0.014	50.755	-69.304
	10.199	8.832	-4.000	0.018	-0.018	56.690	-71.628
	10.799	9.237	-3.625	-0.010	0.015	61.450	-73.925
	11.398	9.009	-3.811	-0.001	-0.018	67.501	-76.122
	11.998	8.820	-3.453	0.018	0.015	72.327	-78.301
	12.598	9.491	-3.611	-0.021	-0.018	78.432	-80.381
	13.197	8.545	-3.315	0.047	0.013	83.374	-82.434
	13.797	9.473	-3.398	-0.040	-0.016	89.472	-84.401
	14.397	8.255	-3.164	0.070	0.010	94.594	-86.329
	14.697	10.521	-2.909	-0.059	0.011	97.365	-87.266

SERIES III CASE 10

	TIME	ZW & CG	Z-FWD CP	Z-REAR CP	NOSE GEAR	MAIN GEAR
[illegible]	0.000	-18.276	-43.930	-47.974	0.000	0.000
[illegible]	14.017	0.000	-26.539	-26.539	8627.326	27100.922
	0.000	0.000	-26.539	-26.539	3483.255	12424.002
	[illegible]	[illegible]	-28.424	-29.376	8431.043	21769.262
	[illegible]	-3.757	-30.438	-30.193	6178.857	13048.986
	1.400	[illegible]	-32.409	-31.969	5658.023	13035.619
	2.000	-7.334	-34.316	-33.085	4563.266	5052.612
	[illegible]	[illegible]	-35.156	-35.312	3939.311	7955.747
	[illegible]	[illegible]	-37.023	-36.034	3770.792	0.000
	4.200	-12.118	-39.649	-38.496	4091.384	0.000
	4.400	[illegible]	-41.375	-40.070	3985.444	0.000
	5.400	[illegible]	-43.015	-41.572	0.000	0.000
	6.000	-15.725	-44.919	-12.954	0.000	0.000
	[illegible]	[illegible]	[illegible]	-44.213	0.000	0.000
	7.200	-17.017	-47.053	-45.293	0.000	0.000
	7.400	-17.032	-48.075	-46.246	0.000	0.000
	8.400	-14.151	-48.859	-46.960	0.000	0.000
	9.000	-14.255	-49.446	-47.538	0.000	0.000
	[illegible]	-14.256	-49.745	-47.829	0.000	0.000
	10.100	-17.052	-49.830	-47.974	0.000	0.000
	10.700	-17.536	-49.574	-47.799	0.000	0.000
	[illegible]	-16.025	-49.294	-47.471	0.000	0.000
	[illegible]	-16.090	-48.563	-46.811	0.000	0.000
	[illegible]	-15.104	-47.547	-45.985	0.000	0.000
	[illegible]	[illegible]	-46.395	-44.840	0.000	0.000
	13.777	-12.053	-44.919	-43.518	0.000	0.000
	[illegible]	-11.252	-43.109	-41.907	0.000	0.000
	14.917	-10.170	-42.245	-41.028	0.000	0.000

SERIES III CASE 10 (Cont'd)

	TIME	U A/C	W A/C	THETA DOT	THETA	X(I) A/C	Z(I) A/C
MINIMUM	0.000	0.000	-3.365	-0.092	-0.024	-0.004	-59.542
MAXIMUM	14.698	21.101	-0.047	0.087	0.034	122.315	-33.000
	0.000	0.000	-1.393	0.005	-0.006	0.000	-33.000
	0.600	0.000	-0.047	0.084	-0.006	0.017	-34.185
	1.200	0.000	-2.737	-0.056	0.005	0.008	-34.834
	1.800	0.000	-1.092	0.038	0.006	0.008	-36.054
	2.400	0.007	-1.775	-0.015	0.015	0.002	-36.738
	3.000	0.404	-1.809	0.012	0.003	0.006	-38.079
	3.600	4.070	-0.525	0.057	0.021	1.296	-38.665
	4.200	7.243	-2.188	-0.053	0.024	4.639	-39.525
	4.800	9.511	-3.116	-0.042	-0.006	9.935	-41.206
	5.400	8.094	-2.870	0.042	0.011	14.964	-43.000
	6.000	9.750	-2.802	-0.047	-0.020	20.861	-41.655
	6.600	7.655	-2.512	0.077	0.003	25.838	-46.206
	7.200	10.453	-2.598	-0.069	-0.016	31.678	-47.611
	7.800	7.753	-2.123	0.087	-0.003	37.016	-48.895
	8.400	11.132	-1.904	-0.087	-0.011	42.851	-50.044
	9.000	9.075	-1.690	0.084	-0.009	48.553	-51.058
	9.600	11.531	-1.504	-0.092	-0.005	54.314	-51.951
	10.200	9.599	-1.235	0.072	-0.015	60.430	-52.695
	10.799	11.533	-0.829	-0.081	0.001	66.156	-53.332
	11.399	9.243	-0.892	0.053	-0.019	72.643	-53.836
	11.999	11.501	-0.337	-0.059	0.006	78.369	-54.174
	12.599	11.149	-0.992	0.081	0.002	85.358	-54.586
	13.199	15.619	-1.651	0.011	0.013	93.367	-55.303
	13.798	20.236	-2.788	-0.038	0.005	104.148	-56.733
	14.398	19.021	-3.331	0.036	-0.011	116.561	-58.607
	14.698	19.268	-2.968	0.058	0.008	122.315	-59.542

SERIES III CASE 11

APPENDIX B

GENERALIZED AIRCRAFT EQUATIONS OF

MOTION

GENERALIZED EQUATION
FOR
SIX DEGREES OF FREEDOM

IN THE LARK-I SIMULATION, THE FOLLOWING VARIABLES ARE SET TO ZERO

ANGLES:

ϕ ROLL ATTITUDE

ψ YAW ATTITUDE

β_s SIDE SLIP ANGLE

A_1 LATERAL CYCLIC TILT

RATES:

p ANGULAR ROLL VELOCITY = $\dot{\phi}$

r ANGULAR YAW VELOCITY = $\dot{\psi}$

v LATERAL VELOCITY = $\dot{y}$

FORCES AND MOMENTS:

$(X)_R$ REAR ROTOR FORCE

All side forces and moments

(a) The X-Force Equation

$$X=(X)_F+(X)_R+(X)_{FUS}+(X)_W+(X)_T+(X)_{VT}+(X)_{TR}+\sum_{i=1}^{n}(X)_{P_i}+W\sin\phi\sin\psi$$

$$-W\cos\phi\sin\theta\cos\psi-\frac{W}{g}(\dot{u}+qw-rv)=0$$

FRONT ROTOR FORCE

$$(X)_F=(L_F\cos A_{1_F}-Y_F\sin A_{1_F})\sin(\alpha-\epsilon_F)-D_F\cos(\alpha-\epsilon_F)\cos\beta_s$$

$$-(L_F\sin A_{1_F}+Y_F\cos A_{1_F})\sin\beta_s$$

REAR ROTOR FORCE

$$(X)_R=(L_R\cos A_{1_R}+Y_R\sin A_{1_R})\sin(\alpha-\epsilon_F)-D_F\cos(\alpha-\epsilon_F)\cos\beta_s$$

$$-(L_R\sin A_{1_R}-Y_R\cos A_{1_R})\sin\beta_s$$

FUSELAGE FORCE

$$(X)_{FUS}=L_{FUS}\sin(\alpha-\epsilon_{FUS})-D_{FUS}\cos(\alpha-\epsilon_{FUS})\cos\beta_s-Y_{FUS}\sin\beta_s+F_{LG}$$

WING FORCE

$$(X)_W=L_W\sin(\alpha-\epsilon_W)-D_W\cos(\alpha-\epsilon_W)\cos\beta_s$$

TAIL FORCE

$$(X)_T=L_T\sin(\alpha-\epsilon_T)-D_T\cos(\alpha-\epsilon_T)\cos\beta_s$$

VERTICAL TAIL FORCE

$$(X)_{VT}=-D_{VT}\cos(\alpha-\epsilon_{VT})\cos\beta_s+L_{VT}\sin\beta_s$$

TAIL ROTOR FORCE

$$(X)_{TR}=Y_{TR}\sin(\alpha-\epsilon_{TR})-D_{TR}\cos(\alpha-\epsilon_{TR})\cos\beta_s-T_{TR}\sin\beta_s$$

POWER PLANT FORCE

$$(X)_{P_i}=T_{P_i}\cos i_{P_i}-N_{P_i}\sin i_{P_i}$$

(b) The Y-Force Equation

$$Y=(Y)_F+(Y)_R+(Y)_{FUS}+(Y)_W+(Y)_T+(Y)_{VT}+(Y)_{TR}+\sum_{i=1}^{n}(Y)_{P_i}+W\sin\phi\cos\psi$$

$$+W\cos\phi\sin\theta\sin\psi-\frac{W}{g}(\dot{v}+ru-pw)=0$$

where

$$(Y)_F=(L_F\cos A_{1_F}-Y_F\sin A_{1_F})\sin(\alpha-\epsilon_F)-D_F\cos(\alpha-\epsilon_F)\quad\sin\beta_s$$

$$+(L_F\sin A_{1_F}+Y_F\cos A_{1_F})\cos\beta_s$$

$$(Y)_R=(L_R\cos A_{1_R}+Y_R\sin A_{1_R})\sin(\alpha-\epsilon_R)-D_R\cos(\alpha-\epsilon)\quad\sin\beta_s$$

$$+(L_R\sin A_{1_R}-Y_R\cos A_{1_R})\cos\beta_s$$

$$(Y)_{FUS}=L_{FUS}\sin(\alpha-\epsilon_{FUS})-D_{FUS}\cos(\alpha-\epsilon_{FUS})\quad\sin\beta_s+Y_{FUS}\cos\beta_s$$

$$(Y)_W=L_W\sin(\alpha-\epsilon_W)-D_W\cos(\alpha-\epsilon_W)\quad\sin\beta_s$$

$$(Y)_T=L_T\sin(\alpha-\epsilon_T)-D_T\cos(\alpha-\epsilon_T)\quad\sin\beta_s$$

$$(Y)_{VT}=-D_{VT}\cos(\alpha-\epsilon_{VT})\sin\beta_s-L_{VT}\cos\beta_s$$

$$(Y)_{TR}=Y_{TR}\sin(\alpha-\epsilon_{TR})-D_{TR}\cos(\alpha-\epsilon_{TR})\quad\sin\beta_s+T_{TR}\cos\beta_s$$

$$(Y)_{P_i}=Y_{P_i}$$

(c) The Z-Force Equation

$$Z=(Z)_F+(Z)_R+(Z)_{FUS}+(Z)_W+(Z)_T+(Z)_{VT}+(Z)_{TR}+\sum_{i=1}^{n}(Z)_{P_i}+W\cos\phi\cos\theta$$

$$-\frac{W}{g}(\dot{w}+pv-qu)=0$$

where

$$(Z)_F=-D_F\sin(\alpha-\varepsilon_F)+(L_F\cos A_{1_F}-Y_F\sin A_{1_F})\cos(\alpha-\varepsilon_F)$$

$$(Z)_R=-D_R\sin(\alpha-\varepsilon_R)+(L_R\cos A_{1_R}+Y_R\sin A_{1_R})\cos(\alpha-\varepsilon_R)$$

$$(Z)_{FUS}=-D_{FUS}\sin(\alpha-\varepsilon_{FUS})+L_{FUS}\cos(\alpha-\varepsilon_{FUS})$$

$$(Z)_W=D_W\sin(\alpha-\varepsilon_W)+L_W\cos(\alpha-\varepsilon_W)$$

$$(Z)_T=-D_T\sin(\alpha-\varepsilon_T)+L_T\cos(\alpha-\varepsilon_T)$$

$$(Z)_{VT}=-D_V\sin(\alpha-\varepsilon_{VT})$$

$$(Z)_{TR}=-D_{TR}\sin(\alpha-\varepsilon_{TR})+Y_{TR}\cos(\alpha-\varepsilon_{TR})$$

$$(Z)_{P_i}=-T_{P_i}\sin i_{P_i}+N_{P_i}\cos i_{P_i}$$

where

q = PITCHING VELOCITY
p = ROLLING VELOCITY
r = YAWING VELOCITY
θ = PITCH ATTITUDE
ϕ = ROLL ATTITUDE
ψ = YAW ATTITUDE
u = VELOCITY ALONG BODY X-AXIS
v = VELOCITY ALONG BODY Y-AXIS
w = VELOCITY ALONG BODY Z-AXIS
α = ANGLE OF ATTACK OF ROTOR
A_{1F} = CYCLIC PITCH
β_s = SIDE SLIP ANGLE
ε = INTERFERENCE DUE TO DOWNWASH
X = FORCE IN DIRECTION OF BODY X-AXIS
L = LIFT FORCE NORMAL TO RELATIVE WIND
D = DRAG FORCE
Y = SIDE FORCE
T = THRUST FORCE
N = NORMAL TO THRUST FORCE
W = WEIGHT

SUBSCRIPTS

F FRONT ROTOR
R REAR ROTOR
FUS FUSELAGE
W WING
T HORIZONTAL TAIL
V VERTICAL TAIL
TR TAIL ROTOR
P POWER PLANT
LG LANDING GEAR

(d) <u>The Rolling Moment Equation (L)</u>

$$L = \sum_{i=1}^{n} (L)_i = \sum_{i=1}^{n} (Z)_i \ell_{Y_i} - (Y)_i \ell_{Z_i} + (L_o)_i \quad + L_I$$

$$L = (Z)_F \ell_{Y_F} - (Y)_F \ell_{Z_F} + (Z)_R \ell_{Y_R} - (Y)_R \ell_{Z_R}$$

$$+ (Z)_W \ell_{Y_W} - (Y)_W \ell_{Z_W} + (Z)_T \ell_{Y_T} - (Y)_T \ell_{Z_T}$$

$$+ (Z)_{VT} \ell_{Y_{VT}} - (Y)_{VT} \ell_{Z_{VT}} + (Z)_{TR} \ell_{Y_{TR}} - (Y)_{TR} \ell_{Z_{TR}}$$

$$+ \sum_{i=1}^{n} (Z)_{P_i} \ell_{Y_{P_i}} - (Y)_{P_i} + Q_{P_i} \quad + L_{FUS} + L_{HUB_F} - L_{HUB_R}$$

$$-\dot{p}\, I_{XX} + I_{XZ}(\dot{r} + pq) + rq(I_{YY} - I_{ZZ}) + I_{XY}(\dot{q} - rp)$$

$$+ I_{YZ}(q^2 - r^2) = 0$$

where i refers to the i^{th} aircraft component and is evaluated by letting i = 1, 2, 3, etc., or the appropriate component designation.

Subscript I refers to inertia terms. Similar notation is used in the pitching and yawing moment equations given below.

(e) <u>The Pitching Moment Equation (M)</u>

$$M = \sum_{i=1}^{n} (M)_i = \sum_{i=1}^{n} (X)_i \ell_{Z_i} + (M_o)_i \quad + M_I$$

$$M = (X)_F \ell_{Z_F} - (Z)_F \ell_{X_F} + (X)_R \ell_{Z_R} - (Z)_R \ell_{X_R}$$

$$+(X)_W \ell_{Z_W} - (Z)_W \ell_{X_W} + (X)_T \ell_{Z_T} - (Z)_T \ell_{X_T}$$

$$+(X)_{VT} \ell_{Z_{VT}} - (Z)_{VT} \ell_{X_{VT}} + (X)_{TR} \ell_{Z_{TR}} - (Z)_{TR} \ell_{X_{TR}}$$

$$+\sum_{i=1}^{n} (X)_{P_i} \ell_{Z_{P_i}} - (Z)_{P_i} \ell_{X_{P_i}} + M_{P_i} + M_{FUS} + M_{HUB_F} + M_{HUB_R} + Q_{TR}$$

$$-\dot{q}\, I_{YY} + I_{XZ}(r^2 - p^2) - rp(I_{XX} - I_{ZZ})$$

$$+I_{XY}(\dot{p} + rq) + I_{YZ}(\dot{r} - pq) = 0$$

(f) <u>The Yawing Moment Equation (N)</u>

$$N = \sum_{i=1}^{n} (N)_i = \sum_{i=1}^{n} (Y)_i \ell_{X_i} - (X)_i \ell_{Y_i} + (N_o)_i \quad + N_I$$

$$N = (Y)_F \ell_{X_F} - (X)_F \ell_{Y_F} + (Y)_R \ell_{X_R} - (X)_R \ell_{Y_R}$$

$$+(Y)_W \ell_{X_W} - (X)_W \ell_{Y_W} + (Y)_T \ell_{X_T} - (X)_T \ell_{Y_T}$$

$$+(Y)_{VT} \ell_{X_{VT}} - (X)_{VT} \ell_{Y_{VT}} + (Y)_{TR} \ell_{X_{TR}} - (X)_{TR} \ell_{Y_{TR}}$$

$$+\sum_{i=1}^{n} (Y)_{P_i} \ell_{X_{P_i}} - (X)_{P_i} \ell_{Y_{P_i}} + N_{FUS} + Q_F - Q_R$$

$$-\dot{r}\, I_{ZZ} + I_{XZ}(\dot{p} - qr) - pq(I_{YY} - I_{XX})$$

$$+I_{XY}(p^2 - q^2) + I_{YZ}(\dot{q} + pr) = 0$$

L = ROLLING MOMENT

M = PITCHING MOMENT

N = YAWING MOMENT

$\ell_{1,2}$ = A distance parallel to an axis designated by subscript 1, from c.g. to force with subscript 2

$$p = \dot{\Phi} - \dot{\Psi} \sin \theta$$

$$q = \dot{\theta} \cos \Phi + \dot{\Psi} \cos \theta \sin \Phi$$

$$r = \dot{\Psi} \cos \theta \cos \Phi - \dot{\theta} \sin \Phi$$

$$\dot{\theta} = q \cos \Phi - r \sin \Phi$$

$$\dot{\Phi} = p + q \sin \Phi \tan \theta + r \cos \Phi \tan \theta$$

$$\dot{\Psi} = (q \sin \Phi + r \cos \Phi) \sec \theta$$

Transformation to Inertial Axes

$$\frac{dx'}{dt} = u \cos \theta \cos \Psi + v(\sin \Phi \sin \theta \cos \Psi - \cos \Phi \sin \Psi) + w(\cos \Phi \sin \theta \cos \Psi + \sin \Phi \sin \Psi)$$

$$\frac{dy'}{dt} = u \cos \theta \sin \Psi + v(\sin \Phi \sin \theta \sin \Psi + \cos \Phi \cos \Psi) + w(\cos \Phi \sin \theta \sin \Psi - \sin \Phi \cos \Psi)$$

$$\frac{dz'}{dt} = -u \sin \theta + v \sin \Phi \cos \theta + w \cos \Phi \cos \theta$$

APPENDIX C

SUMMARY OF

CHARACTERISTICS, FORCES AND MOMENTS

OF THE

CH-53 HELICOPTER

SUMMARY OF

CH-53 CHARACTERISTICS AND PARAMETERS

CHARACTERISTICS

Rotor

R	RADIUS, FT	36
b	NUMBER OF BLADES	6
Ω	ROTATIONAL SPEED, RAD/SEC (NOTE 1)	21.7
σ	SOLIDITY RATIO	.1150
e	FLAPPING HINGE OFFSET, FT.	2.0
θ_t	BLADE TWIST, DEG.	-6°
$\dot{L}_s$	ROTOR SHAFT INCIDENCE, DEG. (LONG.) (NOTE 2)	5°
γ	BLADE MASS FACTOR (LOCKE NO.)	12.55
M_s	FIRST MASS MOMENT OF BLADES, SLUG - FT	183.6
l_{zf}	x,y COORDINATES OF ROTOR HEAD, FT	-7.50
l_{xf}		1.33
$B_{1s_{max}}$	CYCLIC PITCH LIMITS, DEG. (NOTE 3)	16.25
$B_{1s_{min}}$		-11.0
$\theta_{o_{max}}$	COLLECTIVE PITCH LIMITS	15.0
$\theta_{o_{min}}$		0

CHARACTERISTICS

TAIL

A_t	AREA, FT^2	40
i_t	INCIDENCE, DEG.	3.0
$\mathcal{R}$	ASPECT RATIO	2.5
l_{z_t}	COORDINATES, TAIL AERODYNAMIC CENTER	-9.85
l_{x_t}		-25.00

LANDING GEAR

$l_{z_{lg_n}}$	COORDINATES OF GROUND CONTACT POINT	NOSE	8.16
$l_{x_{lg_n}}$			7.08
$l_{z_{lg_m}}$		MAIN	8.16
$l_{x_{lg_m}}$			20.0

AIRCRAFT PARAMETERS

W	WEIGHT, LBS	33500
I_{yy}	MOMENT OF INERTIA IN PITCH SLUG - FT^2	156000
t_a	AMBIENT TEMPERATURE, °F	59.1
K_e	% ENGINE TORQUE	126.

AFCS CONSTANTS

K_P	PROPORTIONAL GAIN	0.8
K_R	RATE GAIN	0.4
K_S	SUMMATION GAIN	0.0

$z_{i_{ac}}$	AIRCRAFT COORDINATES INERTIAL AXES, FT	33.2
$x_{i_{ac}}$		0
$\dot{z}_{i_{ac}}$	AIRCRAFT VELOCITY COMPONENTS	
$\dot{x}_{i_{ac}}$		0
θ	FUSELAGE PITCH, DEG	0.0
$\dot{\theta}$	PITCH RATE, RAD/SEC	0.0
T	THRUST, LBS	36000
B_{1s}	CYCLIC PITCH, DEGS	
θ_o	COLLECTIVE PITCH, DEGS	
θ_t	FUSELAGE TRIM	.014

NOTES

(1) Rotational speed, power on, is maintained between 21.8 rad/sec., max, and 19.4 rad/sec. min. (Ref. 5).

(2) Inclined forward.

(3) Positive cyclic tilts the swash plate counterclockwise.

(4) Parameters can be changed interactively at run time. The procedure is discussed in Chapter III. The values in the table are used unless specifically changed at the beginning of each run.

SUMMARY OF FORCES AND MOMENTS

LANDING GEAR (Section III-1)

NOSE GEAR LOAD VS STROKE (S_N)

$$F_{LG_N} = 173200/(S_N + 4.22) \qquad \text{III-4}$$

MAIN GEAR LOAD VS STROKE (S_M)

$$F_{LG_N} = 93000/(S_M + 0.825) \qquad \text{III-5}$$

DAMPING FORCES

$$F_{LG_D} = + 100\ \dot{S}^2 \qquad \text{III-7}$$

where $\dot{S}$ = stroke velocity. (Subscripts: N=nose, M=main)

STROKE AS A FUNCTION OF AIRCRAFT/SHIP POSITION

(Both gear ¢'s are perpendicular to A/C x-axis)

$$S_N = z_{i_{ac}} - L_{LG} - z_{i_{LP_N}} + l_{x_{LG_N}} \theta_f$$

$$S_M = z_{i_{ac}} - L_{LG} - z_{i_{LP_M}} + l_{x_{LG_M}} \theta_f \qquad \text{III-7.1}$$

where $z_{i_{ac}}$ = A/C

L_{LG} = Distance from cg to landing gear extended, parallel to z axis, same for both gears.

$z_{i_{LP}}$ = Launch/landing pad contact point (inertial frame)

$l_{x_{LG}}$ = Distance in x direction, landing gear contact point to cg.

θ_f = Pitch angle, fuselage, positive nose up.

STROKE VELOCITY AS A FUNCTION OF A/C AND SHIP VELOCITY

$$\dot{S}_N = \dot{z}_{i_{LG_N}} - (\dot{z}_{i_{ac}} + \dot{\theta}_f l_{x_{LG_N}})$$

$$\dot{S}_M = \dot{z}_{i_{LG_M}} - (\dot{z}_{i_{ac}} + \dot{\theta}_f l_{x_{LG_M}}) \qquad \text{III-7.2}$$

ROTOR FORCES, ANGLE OF ATTACK, ENGINE POWER (Section III-2)

1. THRUST COEFFICIENT

$$C_T = \frac{W\ (T_R/W)}{\pi R^2 \rho\ (\Omega R)^2} \qquad \text{III-8}$$

CT = Thrust coefficient

W = Gross wt., lbs

T_R = Rotor radius, ft.

R = Rotor radius, ft.

ρ = Mass density of air, slugs/ft^3

Ω = Rotor rotational velocity, rad/sec^2

2. COLLECTIVE PITCH, θ_o

$$\theta_o = \frac{D}{N}$$

$$\begin{aligned} D = {} & [a(t_{4,2} + t_{4,3}) - \delta_2(t_{5,6} + t_{5,7})] \\ & -\delta_1(t_{5,3} + t_{5,4}) + (at_{4,5} - \delta_2 t_{5,9})\theta_t \\ & + 2\ (at_{4,6} - \delta_2 t_{5,10}) \end{aligned} \qquad \text{III-12}$$

$$\begin{aligned} N = {} & 2\delta_2\ (t_{5,8} + t_{5,9} + t_{5,10}) - 2a(t_{4,4} + t_{4,5} + t_{4,6}) \\ & + \frac{t_{3,2} + t_{3,3}}{t_{3,1}} [\delta_2\ (t_{5,6} + t_{5,7}) - a(t_{4,2} + t_{4,3})] \end{aligned} \qquad \text{III-13}$$

$t_{i,j}$ are the coefficients from Bailey's rotor analysis, Reference 13.

δ_i are the coefficients in the section drag equation =

$c_{d_o} = \delta_o + \delta_1 \alpha_r + \delta_2 \alpha_r^2$ (Reference 12)

Rotor Forces (Continued)

$$Q_R = C_Q \ (\pi R^2 \rho (\Omega R)^2 \qquad \text{FT-LBS} \qquad \text{III-14}$$

4. POWER REQUIRED

$$P_R = (Q_R \Omega)/550 \qquad \text{III-15}$$

Power available (maximum)

$$P_{A_{max}} = 6422 \text{ shp.} \quad t \leq 15°c$$

$$= 6858 - (29.1)t \quad 15° > t > 59°c \qquad \text{III-16}$$

$$= 5140 \quad t \geq 59°c$$

5. ROTOR ANGLE OF ATTACK

$$\alpha_c = \text{arc tan}\left[\frac{\lambda}{\mu} + \frac{C_T}{2\mu \ (\mu^2 + \lambda^2)^{1/2}}\right] \qquad \text{III-17}$$

6. THE H-FORCE

$$H = \frac{-T(\sin \alpha_c - \frac{D}{L} \cos \alpha_c}{\cos \alpha_c + \frac{D}{L} \sin \alpha_c} \qquad \text{III-18}$$

$$\frac{D}{L} = \frac{\sigma a}{2\mu}\left[\frac{\delta_o}{a} t_{6,1} + \frac{\delta_1}{a} (t_{6,2}\lambda + t_{6,3}\theta_{.75})\right.$$

$$\left. + \frac{\delta_2}{a} \ (t_{6,5}\lambda^2 + t_{6,5}\lambda\theta_{.75} + t_{6,8}\theta^2_{.75})\right]$$

For these studies, the following values were used

$\delta_o = 0.0087$

$\delta_1 = -0.0216$

$\delta_2 = +0.400$

a is the slope of the section lift curve = 5.73

θ_t is the blade twist

Rotor Forces (Continued)

3. TORQUE COEFFICIENT C_Q

$$\lambda = \frac{1}{t_{3,1}} \left[\frac{C_T}{\sigma a} - t_{3,2}\theta_o - t_{3,3}\,(\theta_o + \theta_t)\right] \qquad \text{III-10}$$

$$C_Q = K_1\theta_o^2 + K_2\theta_o + K_3\lambda\theta_o + K_4\lambda^2 + K_5\lambda + K_6 \qquad \text{III-9}$$

$$K_1 = (\delta_2 t_{5,8} + at_{4,4}) + (\delta_2 t_{5,9} - at_{4,5}) + \delta_2 t_{5,10}$$

$$K_2 = \delta_1 t_{5,3} + \delta_1 t_{5,4} + (\delta_2 t_{5,9} - at_{4,5})\theta_t + 2at_{4,6}$$

$$K_3 = (\delta_2 t_{5,6} - at_{4,2}) + (\delta_2 t_{5,7} - at_{4,3})$$

$$K_4 = (\delta_2 t_{5,5} - at_{4,1})$$

$$K_5 = \delta_1 t_{5,2} + (\delta_2 t_{5,7} - at_{4,3})\theta_t$$

$$K_6 = \delta_o t_{5,1} + \delta_1 t_{5,4}\theta_t + \delta_2 t_{5,10}\theta_t^2$$

where σ = solidity ratio

λ = inflow ratio $[(V \sin \alpha - \nu)/\Omega R$

and $C_T, \delta_i, t_{i,j}, a, \theta_o$ and θ_t are defined above

C_Q = torque coefficient

$$= \frac{Q}{\pi R^2 \rho\ (\Omega R)^2 R}$$

$$L_F = T \cos \alpha_c - H \sin \alpha_c \qquad \text{III-19}$$

$$D_F = H \cos \alpha_c - T \sin \alpha_c \qquad \text{III-20}$$

ROTOR HUB MOMENT Section III-3

$$M_H = K(a_1 - B_{1s}) - \left(\frac{ae}{12R}\right)\left(\frac{\dot{\theta}_f}{\Omega}\right)\left[1 - \left(\frac{e}{R}\right)^3\right] \quad \text{III-21}$$

$$K = \frac{eb\Omega^2 M_s}{2}$$

$$a_1 = t_{1,4}\lambda + t_{1,5}\theta_o + t_{1,6}\theta_1$$

where e = flapping hinge offset, ft.

B_{1s} = cyclic pitch, rad.

a = section lift slope

M_s = mass moment of blades, slug - ft.

a_1 = second Fourier flapping coefficient, (tip-path tilt) in flapping equation

$\beta = a_o - a_1 \cos\psi - b_1 \sin\psi - \cdots$

(Ref. 12)

FUSELAGE FORCES AND MOMENTS (Section III-4)

LIFT $L_F/q = 15.0 + 487\ \alpha_F$ III-24

DRAG $D_F/q = 41.696 - 11.45\ \alpha_F + 4.423\ \alpha_F^2$ III-25

for $-20° \leq \alpha_F \leq +20°$

$\alpha_F = \theta_P - \epsilon_{FUS} - \gamma$ = fuselage angle of attack

ϵ_{FUS} = interference of rotor on fuselage

q = dynamic pressure = $1/2\rho V^2$

γ = angle of climb

= arc tan $\frac{U}{W}$

Fuselage Forces and Moments (Continued)

u = velocity in x direction

w = velocity in z direction

$v = \sqrt{(u^2 + w^2)}$

Moment $M_F/q = -450 \quad -20° \leq \alpha_F \leq -12°$ III-26

$= 58.8\alpha_F \quad -12 < \alpha_F < +16°$ III-27

$= 1000 \quad 16° \leq \alpha_F \leq +20°$ III-28

TAIL FORCES AND MOMENTS (Section III-5)

$$C_{L_T} = a(\alpha_T - \alpha_O)$$

$$\alpha_T = \theta_f + i_T - \varepsilon_T - \varepsilon_p$$

$$a = C_{LT_\alpha} = \frac{\pi A\!R}{1 + \sqrt{\left[\left(\frac{\pi A\!R}{a_O}\right)^2 + 1\right]}}$$

where

where i_T = Tail incidence, pos. L.E. up

a_O = zero lift incidence

ε_T = interference angle, rotor downwash on tail (see below)

ε_p = change in angle of attack due to pitching velocity of fuselage

$= \frac{\dot{\theta}_f l_{x_T}}{V}$

l_{x_T} = distance of tail (1/4 pt. MAC) to cg FT.

V = flight path speed = $\sqrt{(u^2 + w^2)}$

$A\!R$ = aspect ratio

APPENDIX D

THE REPRESENTATION OF RANDOM SEA

D-1 THE EQUATIONS OF SHIP MOTION

If it is assumed that the motions of an arbitrary ship are linear and harmonic, the six linear coupled differential equations of motion can be written in the following abbreviated form:

$$\sum_{k=1}^{6} [\bar{M}_{jk}\ddot{\eta}_k + B_{jk}\dot{\eta}_k = C_{nk}\eta_k + F_j e^{i\omega t}; \quad j = 1 \cdots 6 \qquad \text{D-1}$$

where the six displacements are each denoted by η_k where the subscripts from 1 to 6 refer respectively to surge, sway, heave, roll, pitch and yaw.

It is not our intention to discuss the derivation or solution of equation D-1 or the meaning of the coefficients M, B and C. Experience with these types of equations are assumed and it is sufficient to say that M is a matrix of mass terms augmented in some fashion by the added mass of the displaced water, B is a matrix of damping constants and C is a matrix of hydrostatic restoring coefficients. For a ship with lateral symmetry under the assumption noted above, the surge, heave and sway equations may be solved independently of the other three, and the solutions of all six equations will be simple harmonic functions

$$\eta_j = A_j \cos(\omega t + \epsilon_j) \quad j=1,\cdots 6 \qquad \text{D-2}$$

if the forcing function, or the equation of the wave ($F_j e^{i\omega t}$) can be expressed in the simple harmonic form

$$F \cos \omega t \qquad \text{D-3}$$

where F is the amplitude of the wave

ω is the encounter frequency

A_j is amplitude of the ship response.

We will only be concerned with equations D-2 and D-3 and for all other matters, the reader is referred to References 1 - 3 and especially Reference 15 which is a thorough and exhaustive discussion of the derivation and solution of Equation D-1.

Equation D-2 is the <u>sinusoidal</u> response of the ship at a given frequency ω to a sinusoidal wave of form D-3. In the next section, it will be shown that the real sea profile can in no realistic way be represented or approximated by the form D-3. The real sea can in no way known be represented either as instantaeous profiles

$$Z = F(x)$$

$$Z = F(x,y)$$

or as time histories

$$Z = F(x,t)$$

$$Z = F(x,y,t)$$

where the representation F is a sum, finite or infinite, of periodic functions, sinusoid or other, or polynomials such that the error

$$e = F - G(x,y,t)$$

between the representational function F and a measured profile of wave amplitudes G is either less than a preassigned value, or is a mathematical function, analytic or not, of any of the variables. This is, perhaps, the broadest statement that can be made in mathematical terms of what appears to be a truth which can be stated in less mathematical terms as follows: it does not appear to be possible with the mathematical tools we have at hand to make a mathematical deterministic model of the profile of the sea surface which is a function of no more than a few variables, say 5 or 6. If the variables are limited to x, y, z and t, it is clearly impossible. Even if other variables are added such as wind strength, wind duration, wind direction, fetch length, boundary values of coasts or water depths, etc., a deterministic model is still impossible.

If this is true, the engineer has a problem. In nearly all important cases, in dynamics, the equations which he deals with are equations of motion or are derived from equations of motion, and have the form of equation D-1. The statements made in the prior paragraph mean that the expression $F_j e^{i\omega t}$ cannot be used to represent real waves. The statements seem to go much further: since there is no deterministic way (that is a deterministic function of a few variables) of realistically representing a forcing function in equation D-1, then there is no way of comparing a solution of equation D-1 with what may occur in reality. For example, we can calculate the motions of a ship in the sinusoidal wave $a_o \cos \omega t$; we can measure the motion in a towing tank where such a "pure" wave shape can be generated, and compare the results. This is done in Reference 1 through 3. But we cannot compare the motion in a real sea with the calculated motion in "pure" waves. It was said above that the statements in the prior paragraph "seem" to be saying this, but this, fortunately, is not altogether true. There is some truth but it is not the complete truth. In what follows, it will be shown that a statistical (as opposed to deterministic) use of the solution of Equation D-1 can be derived using a statistical representation of the real sea. The theory of the statistical representation of the random sea is rather simple. There are some serious problems in using the theory, beyond the scope of this brief survey, but which are largely concerned with how we measure wave amplitudes. It is important to remember that the statistical model is completely empirical. The deterministic model is partly empirical.

We have dwelt upon this at some length because the reconciliation of the deterministic model, exemplified by Equation D-1, of ship motions, and the statistical model of wave motions discussed below, although not difficult to understand, can lead to serious misconceptions as to what the results really mean. In most cases, the true meanings are probabilistic: "an amplitude of a given value will be exceeded only in a given time." What, then, is the meaning of choosing one amplitude rather than another? Answers to this and other questions will be attempted in the following discussion.

D-2 The Nature of the Irregular Sea

A typical contour plot of the sea is shown in Figure D-1. The smallest circles locate the highest (or lowest) points. One should be impressed by the disturbing irregularity of the pattern, disturbing, that is, to an applied mathematician.

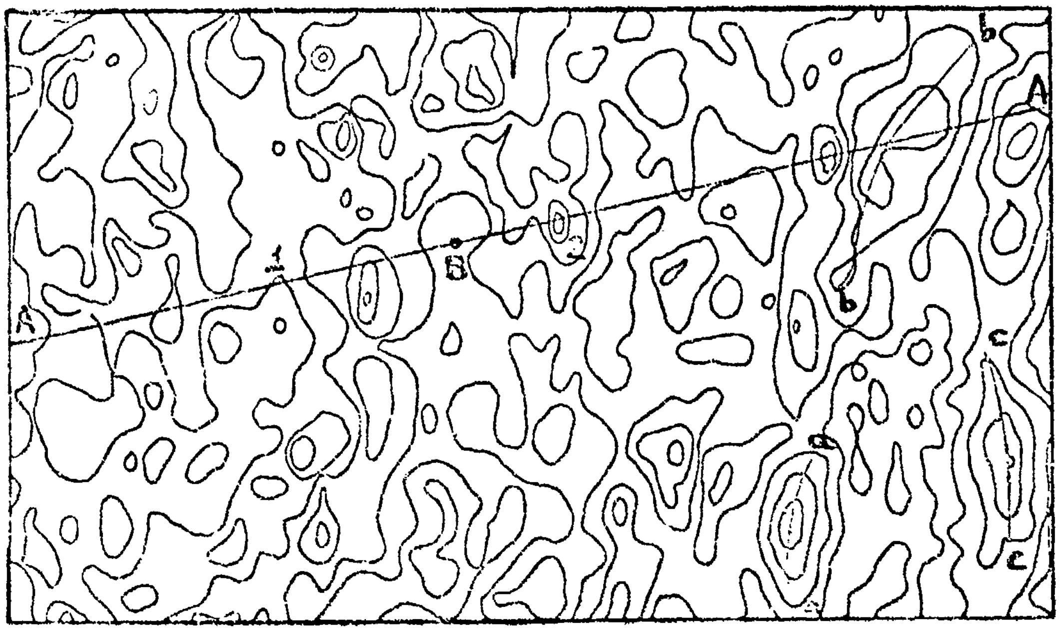


Figure D-1 Typical Contour Plot of the Sea

The picture is very messy no matter which way you hang it. If the pattern appears to have a prevailing motion (say, from left to right) we might expect the crests (and troughs) to extend indefinitely at right angles to the motion. They obviously do not. This attribute of the wave pattern is known as short crestedness, since no one crest extends very far and another appears not far away. These short crests are not aligned with each other, or of the same length or height. (Compare crests a-a, b-b, and c-c). The contours of Figure

D-1 are contemporaneous and if one were to record a multitude of such plots at succeeding instants of time and if it were possible to follow the history of each contour, it would appear as if the various crests were moving at different velocities and in different directions, although the entire pattern 'seems' to have a prevailing speed and direction. Also, crests are not very durable. They appear and disappear and their total life may not be very much longer than the apparent "period" of the wave.

If a cut is taken along some line AA, the resulting profile might look like Figure D-2.

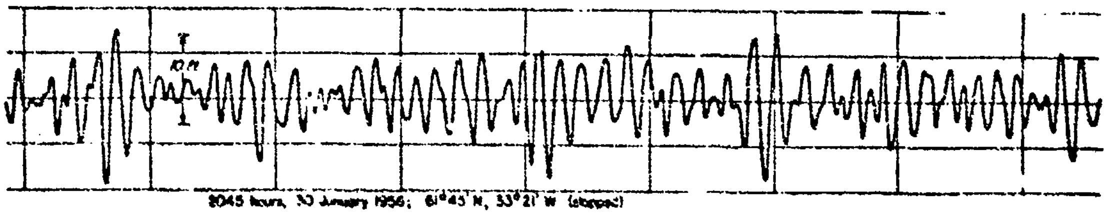


Figure D-2 Typical Wave Profile

This is the same kind of profile which might be measured by a wave height measuring device over a period of time. That is, the spatial profile of a wave pattern looks similar to that measured at a point (say B) as the waves move past.

The profile of Figure D-2 seems easy enough to understand. Let us say it was made by observing the height of the water on a staff fixed in some fashion to the ocean floor. Needless to say, this is not how the record was obtained but the remarks made below apply in any case.

Although Figure D-2 looks simple, it is enormously difficult to interpret. The "waves" are coming from many directions although there seems to be some kind of prevailing direction. The crest lengths are all different. Point 1 moving past B is only the low end of a crest, but Point 2 is a high point. Furthermore, the crests are moving at different speeds although they give the appearance of moving in groups. A stone, for example, thrown in a still pond induces a wave train that travels toward the shore at a steady "group" velocity. But the wave lengths are shorter in the rear and longer in front. If you follow a crest, say the last, you will find that it is very quickly the next to last. As new crests appear at the rear, old crests traveling more slowly disappear at the front. This is an example of a single group speed but differing individual or "phase" speed. The phase speed, c, is related to length (for the pure deep water sinusoid) by the expression

$$c = \frac{L}{T} = \sqrt{\frac{g}{2\pi} L} = \frac{g}{2\pi} T$$

where T is the period and L is the wave length.

Figure D-3 shows the observed frequency distribution of apparent wave periods T (from Reference 16 in the form of a histogram.

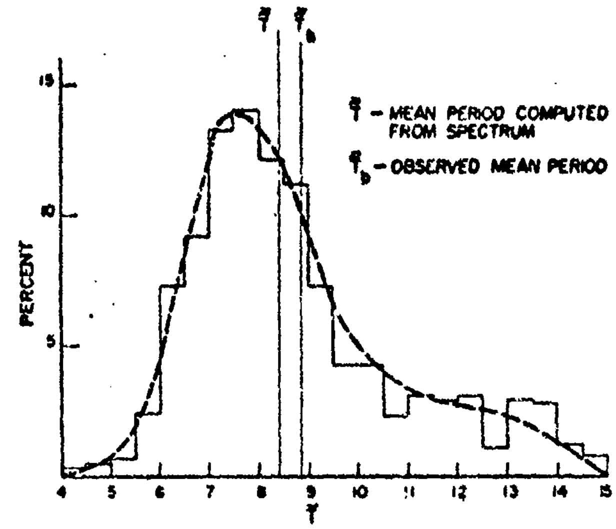


Figure D-3 Observed Frequency Distribution of Apparent Periods of Waves in a Typical Irregular Sea

If this distribution is measured at several times during a "steady" sea state, and each histogram is compiled from records of apparent period observed during a given period, and the increments T (in this case 1/2 sec.) are the same, the histograms will all have approximately the same shape. Although this suggests the superiority of statistical over deterministic methods, the frequency distribution does not provide enough information.

It is apparent from Figure D-3 that observed frequencies are continuously distributed from (in this case) about

$$\omega_{max} = \frac{2\pi}{4} = 1.5 \qquad (T = 4 \text{ secs.})$$

$$\omega_{min} = \frac{2\pi}{15} = 0.42 \qquad (T = 15 \text{ secs.})$$

(The actual bandwidth is somewhat larger, as we shall see. The data in Figure D-3 corresponds roughly to a sea state 5 or 6.)

A similar histogram could be derived from a single record such as Figure D-2, or a collection or ensemble of records, which furnish the distribution of wave heights. In the classical theory, however, there is no relation between wave period and wave height, except that the height-to-length ratio is limited to about 1/7 (Ref. 20).

Joint distributions are equally unrewarding. What appears below is an example from Reference 22.

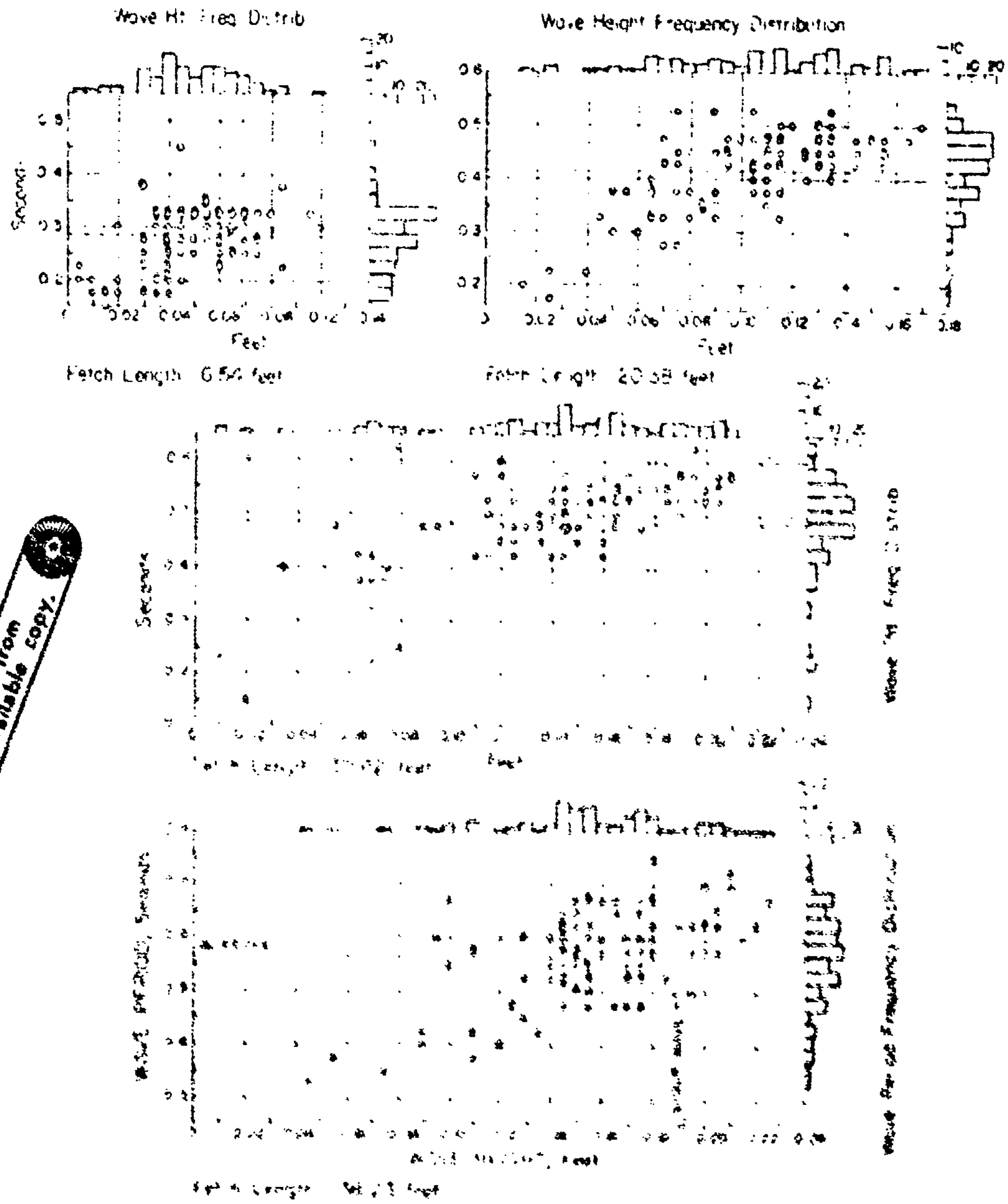


Figure D-4 Joint Frequency Distribution of Wave Period and Wave Height (U = 42.7 ft/sec)

These histograms are for very small waves (2.9" max) that might appear on a pond or sheltered bay. Although the periods seem clustered about the average period, the lengths are very widely distributed about the "single wave" height.

A brief attempt has been made in this section to expose the enormous complexity of sea waves. In terms of a possible mathematical description, the sea is very irregular. Despite this, the conviction that a mathematical description is possible is greatly strengthened by the observation that over a wide area, for periods of several hours, the sea may maintain an appearance which defies description in terms of "average" or "typical" wave lengths, or periods, but <u>nonetheless appears to be steady</u>.

D-3 The Specification of the Irregular Sea

Numerous mathematical models for describing a real sea state have been proposed but all have proved to be inadequate except the description in statistical terms using the concept of the continuous energy spectrum.

It is very hepful in understanding the need for a statistical description, to examine the deterministic models. It will be seen in each case that despite the deterministic character of the describing function in terms of specified amplitudes and frequencies, each method assumes information which can only be provided by statistical analysis of actual records. It should be noted that if any of the models described below were adequate, it could be used to provide wave forcing functions in equation D-1, since the solutions for these equations are for a single periodic wave of specified amplitude and frequency. The complete solution for an aperiodic wave consists of the superposition of an infinite (or in the practical case, a very large) number of regular waves, in a manner which will be discussed in the next section.

Consider the wave record of Figure D-5.

(1) This may be represented by a periodic wave whose amplitude and frequency has some significant relation to the irregular wave. It is suggested by Sverdrup and Munk (Ref. 21) that this can be done with a regular wave

$$r(t) = r_m \cos\left(\frac{2\pi t}{T} + \epsilon\right)$$

wherein r_m and τ are the average amplitude and period of the one third highest waves. The representation is shown in Figure D-5.

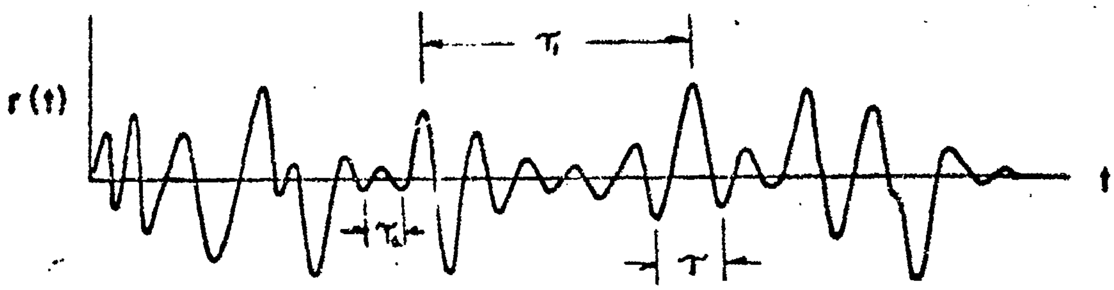
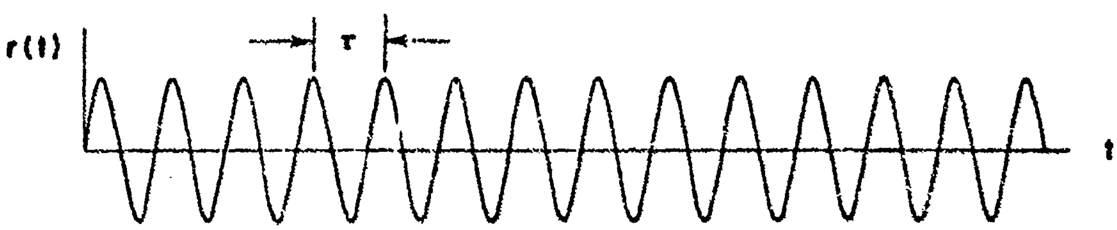


FIG. 1.2.—ACTUAL WAVE RECORD



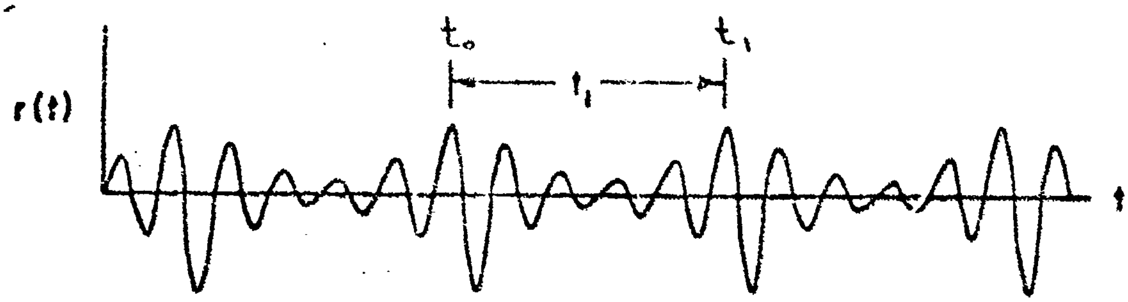
$$r(t) = r_m \cos\left(\frac{2\pi t}{\tau} + \epsilon\right) = r_m \cos(\omega t + \epsilon)$$

$$r(t) = r(t+\tau)$$

Figure D-5 Periodic Wave System with an Amplitude Component at a Single Spectral Frequency

A serious shortcoming of this representation is that about five sixths of the time the actual wave heights will be lower than the significant height of the idealized wave. A more serious fault lies in the selection of the period τ. A ship acts as a narrow band filter, responding only to periods near the natural period τ_n. If τ is too much greater or less than τ_n, very little motion will result. But the actual wave record of figure D-5 contains wave components of all frequencies and although the amplitude of a wave of period $\tau \cong \tau_n$ may be quite small in comparison to r_m, its effect on the motion of the ship may be quite large. The idealization of Figure D-5 has filtered out these components.

(2) The irregular wave could be represented by a Fourier series with various amplitude components at many discrete spectral frequencies. This representation is shown in Figure D-6.



$$r(t) = \sum_{n=1}^{N} r_n \cos\left(\frac{2\pi n t}{t_1} + \epsilon_n\right)$$

$$= \sum_{n=1}^{N} r_n \cos(\omega_n t + \epsilon_n)$$

$$r(t) = r(t + t_1)$$

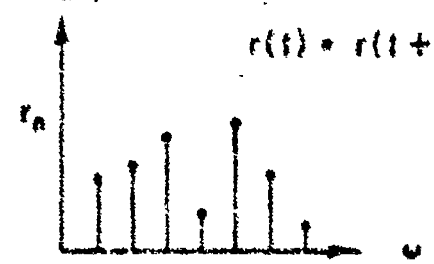


Figure D-6 Periodic Wave System with Amplitude Components at Many Discrete Spectral Frequencies

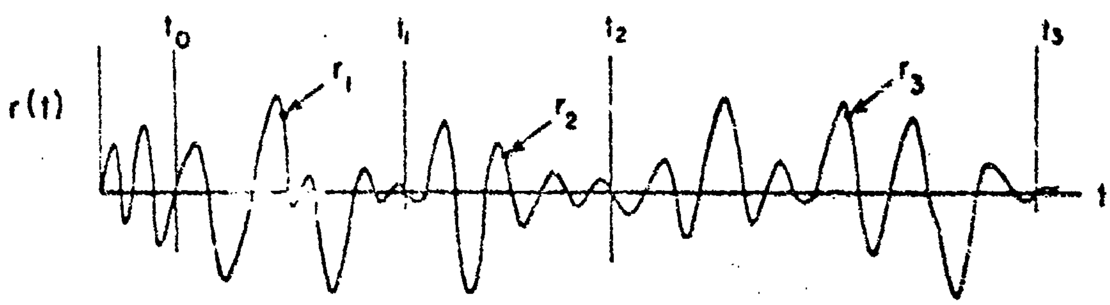
It is based on a harmonic analysis of the actual wave record of Figure D-6 for the period t_1, and for that period only is an exact representation for the limit case where $n \to \infty$ and can be made as exact as desired by taking N as large as necessary. But there is a severe practical limitation. In actual wave records, the amplitudes of harmonic components are neglible for periods less than 25 seconds which means that for $n < (t_1/25)$, all terms would drop out. The harmonics of maximum amplitude will have a period which is greater than the waves of significant (one third highest waves). The amplitudes of higher harmonics with periods less than 3 seconds would be neglible. Thus if t_1 were chosen as

t_1 =	400 seconds	30 minutes
Neglected lower harmonics, $n = 1$, to	4	70
Neglected higher harmonics, $n >$	30	600

The significant portion of the Fourier series for the 400 second case consists of about $30 - 4 = 26$ terms, and for the 30 minute case of about $600 - 70 = 530$ terms. Now it is also true that low actual waves in the Fourier series representation are caused by the phase cancellation of large numbers of harmonic components of small amplitude and large actual waves are caused by phase reinforcement of the same components. The phase angles ϵ_n can be determined exactly by harmonic analysis for the given period $t_0 - t_1$, but will necessarily differ for any other time period.

(The temptation for engineers to think in terms of this model is unbelievably strong. After reading to the end of this appendix, the reader should consult Reference 23. In this paper, the author accepts the inevitability of a statistical description in terms of the energy spectrum, but reverts to a function of the form shown in Figure D-5 to approximate the spectral distribution!)

(3) A third possibility for the description of actual wave records is by use of the Fourier integral. Such a representation is shown in Figure D-7.



$$r(t) = r_0(t) + r_1(t - t_1) + \dots r_n(t - t_n)$$

$$r_n(t) = \int_0^{\infty} a_p(\omega) \cos \omega t \, d\omega + \int_0^{\infty} b_p(\omega) \sin \omega t \, d\omega$$

$$a_p(\omega) = \frac{1}{\pi} \int_{-\infty}^{\infty} r_p(t) \cos \omega t \, dt$$

$$b_p(\omega) = \frac{1}{\pi} \int_{-\infty}^{\infty} r_p(t) \sin \omega t \, dt$$

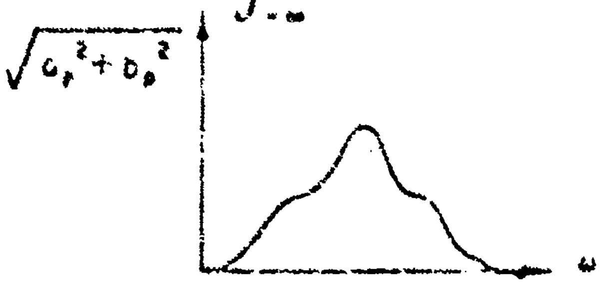


Figure D-7 Aperiodic Wave System Having a Continuous Amplitude Spectrum

In this manner r(t) can be made to represent the actual wave record over any length of time chosen for analysis and this representation would be exact for the interval analyzed. It would fail, however, for time outside the interval in which the analysis was performed, since the record would either have to be defined as identically equal to zero or would remain unknown.

One disadvantage of this method is that there is no known precise procedure by which, starting with a wave record, it is possible to determine the appropriate $a_p(\omega)$ and $b_p(\omega)$. Nevertheless, such a procedure is theoretically possible. The Fourier Integral method would be a convenient one for studying proble in transien response. It does not, however, lend itself to problems of the seaway because of the extremely long duration of the records to be analyzed.

The three models discussed above replace an actually measured wave profile of some definite length with a harmonic approximation. The most serious fault in each method is that the information termined in each case applies only to a specified time interval. The essential irregularity of the sea is never adequately accounted for, although the approximation to a given record could theoretically be made as close as desired. In addition there are in each case practical difficulties which have been described which seriously vitiate the usefulness of those methods.

However, for any given sea state, over appreciable lengths of time, as mentioned above, there is a "steady state" appearance of the sea. This has led oceanographers to make use of the concept of the energy spectrum, exploiting the statistical representation of a random process in a form similar to that developed in communication theory by Tukey and Hamming, Reference 17 and Wiener, Reference 18.

The motive in discussing the three mathematical models described above is not only to exhibit their inadequacies and the need for a random statistical approach as will be described below but to clarify a loss of detail which must be accepted as a consequence of the use of the statistical method. Although in every way favorable to the "deterministic" models described above, the energy spectral method requires that the phase angles are random and independent.

D-4 The Statistical Representation of the Random Sea

According to this representation, the wave amplitude at a point can be represented by the integral

$$r(t) = \int_0^\infty \cos\left[\omega t + e(\omega)\right] \sqrt{\left|S_s(\omega)\right|^2 d\omega} \qquad \text{D-5}$$

It will not be necessary to use this integral (which is not an integral in the ordinary sense). This integral, which can be approximated as closely as required by a sum of difference equations, is distinguished from the previous described models by the random nature of the phase shifts $e(\omega)$ which are equally probable and equally independent.

The most important term in equation D-5 is the spectral energy $S_s(\omega)$. The meaning of this term may be visualized by examining Figure D-8.

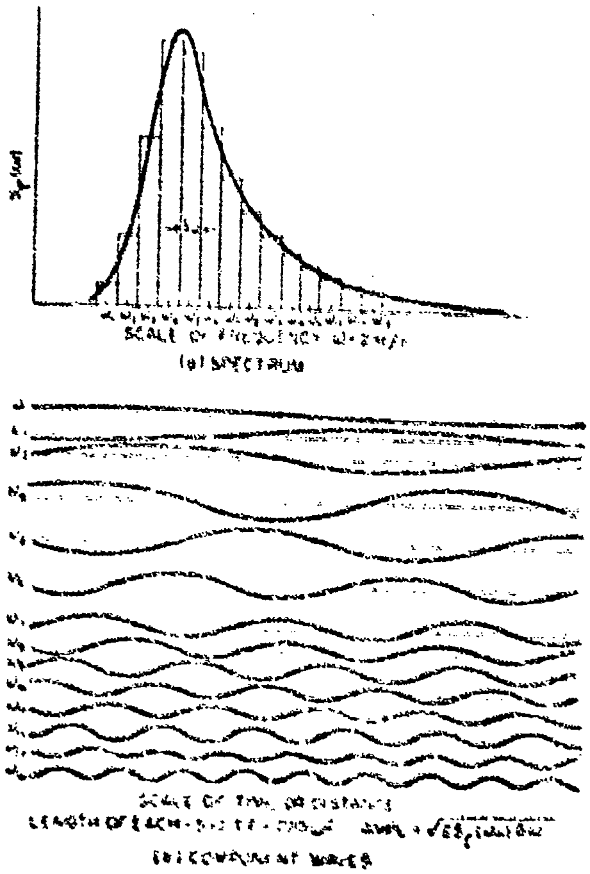


Figure D-8 Typical Energy Spectrum Showing Approximation by a Finite Sum of Components

Here it is assumed that the typical wave record r(t) is composed of a large number of sinusoidal components and that the elevation of the sea surface at any time t may be represented by the sum

$$r(t) = \lim_{\substack{\omega_n \to \infty \\ \delta\omega \to 0}} \sum \cos\,[\omega_n + e(\omega_n)]\,[2S_s(\omega)\,\delta\omega]^{1/2} \qquad \text{D-6}$$

The term $S_s(\omega)$, a continuous function of wave frequency, and is referred to as the spectral density. It comprises the totality of the statistical description of the sea state. In Figure D-8, it can be seen that $S_s(\omega)$ is a function which for any increment $\delta\omega$ is proportional to the total wave energy in that increment. In fact for the increment $\delta\omega$ at the central frequency ω_n, the total energy is

$$\rho g\ [S_s(\omega)\ \delta\omega] \qquad \text{D-7}$$

where ρ is the density and g is the acceleration constant. The total energy of the wave system represented by all the component energies in the spectrum is given by the integral

$$\rho g \int_0^\infty S_s(\omega)\,d\omega$$

This integral, which represents the area under the spectral curve of Figure D-8, is usually called E and hence the total energy is $\rho g E.S_s$ has the units of (length^2 x time).

While the energy spectrum $S_s(\omega)$ has the appearance of an amplitude spectrum, it is different in a very significant way which explains its unique ability to characterize the random sea. The potential energy of a single sinusoidal wave (per unit length of crest) can be represented by

$$1/2\rho g r^2$$

where r is the wave amplitude. It follows, then that at a given central frequency ω_n, a fictitious wave having the same energy as represented by equation D-7 would have the height

$$r_n = [2S_s(\omega)d\omega]^{1/2}$$

The spectral density $S_s(\omega)$, however, represents the cumulative effect of all measurable amplitudes in the increment $\delta\omega$ centered at ω_n.

$S_s(\omega)$ can be readily determined from amplitude time histories such as Figure D-3. The energy spectrum is in fact the Fourier transform of the autocorrelation function of a given amplitude time history. Thus

$$S_s(\omega) = \frac{1}{2\pi} \int_0^\infty r(t)\ r(t-\tau)\ e^{-is\tau}d\tau \qquad \text{D-8}$$

where τ is a continuously varying time lag.

There are two cardinal points to keep in mind in assessing the value of the spectral density method. The function r(t) given by equations D-5 and D-6, although it represents a statistically valid profile will not be used in the subsequent development of ship motions. Only the spectral density $S_s(\omega)$ is required. As will be shown in the next section, this approach provides a statistical description of ship

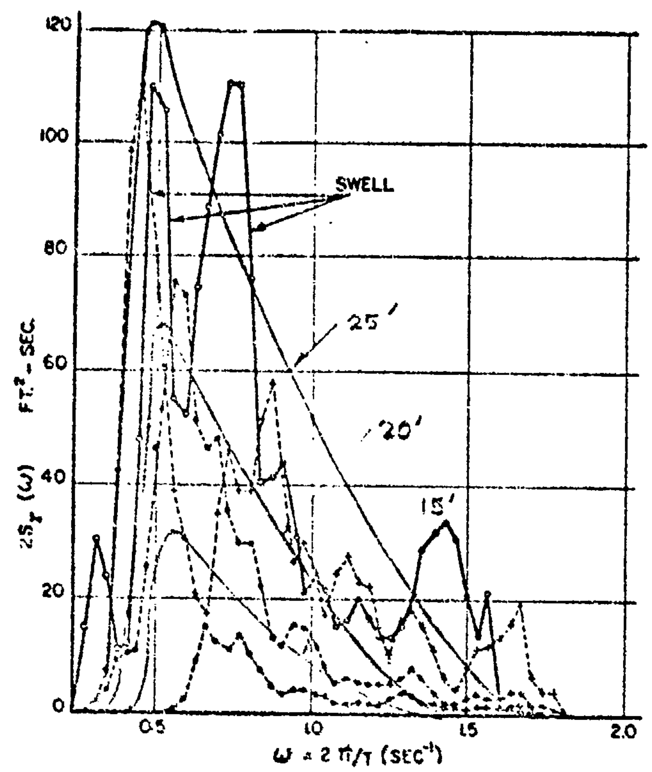


Figure D-9 Typical Sea Spectra

motions in the frequency domain. The implication of this, which has been alluded to above, is that this approach discards all information which relates to the relative phase of the various frequency components. The effect of this will be to introduce a degree of indeterminacy in the equations of aircraft motion whose importance will be very hard to assess.

D-5 Ship Motions in an Irregular Sea

The solutions of equation D-1 for each frequency are linear solutions of the form D-2. If we knew the harmonic components of each frequency band δ_{ω} in Figure D-9, specifically the amplitude of each component ω_i then we could combine the motions by the principal of superposition and determine a total motion which applies to all forcing functions present in the sea pattern. This, however, requires that we must use one of the three deterministic models shown in Figures D-5, D-6, and D-7. These are, in fact, the deterministic models which cannot be used for the reasons discussed in the previous section. The use of the sea energy spectrum of one of the experimental forms shown in Figure D-9 requires that we use the statistical information which these spectra contain in a manner which is within the applicability of the principal of superposition.

The statistical sea energy spectral data is used with the solutions of equation D-1 in the following way: A spectrum of ship response amplitudes as a function of (encounter) frequency is determined by the use of the energy spectrum $S_s(\omega)$ and the ship response operator $r(\omega)$ by the formula

$$S_R(\omega) = r(\omega)\ S_s(\omega) \qquad \text{D-9}$$

The ship response operation is defined as the squared value of the response $\eta_j(\omega)/A_j(\omega)$ (see equation D-2)

$$r(\omega) = [\eta_j(\omega)/A_j(\omega)]^2$$

for each significant value of ω. Using the symbol $[R(\omega)]^2$ for $r(\omega)$, equation D-9 may be written

$$S_R(\omega) = [R(\omega)]^2 \cdot S_s(\omega)$$

a form in which it often appears in the literature. (See, for example, p. 31 of Reference 2, and page II-8, this report.)

The individual results in the calculation of equation D-9 are illustrated in Figure D-10 and will be explained in some detail below. Figure D-10 shows the application of the principle of superposition for sea spectrum at a fixed point (Figure D-10(a)) for two typical ships: a 250' ship moving at 7.97 knots (Froude number Fr = 0.15) and a 500' ship moving at 11.27 knots (Fr = 0.15). In terms of the frequency of encounter, ω, the energy spectra are shifted to the right by the transformation

$$\omega = \omega_o \left(1 = \frac{\omega_o U}{g}\right)$$

where ω_o is the wave frequency and U is the ship speed. In addition, as explained in Reference 3, the spectral amplitudes are transformed by multiplying each amplitude by the Jacobean of the transformation:

$$\frac{1}{\left(1 + \frac{4\omega}{g} U\right)^{1/2}}$$

Naturally, the total areas under the original and transformed curves are identical. In Figure D-10b the curves are smoothed curves drawn through a large collection of individual solutions to equation D-1. For example, at the center frequency $\omega_n = 0.8$, Figure D-10b shows that the ship response in pitch, scaled by the wave amplitude A_5 is about (for the 250' ship),

$$(\theta/\zeta)^2 = 2 \times 10^{-4} \quad (= \eta_5/A_5)^2$$ (Continued page D-25)

Notes for Figure D-10:

(1) The units of each of the sets of curves are as follows:

Fig. 9(a) = Units of $S_s(\omega)$ are FT^2 - SEC.

Fig. 9(b) = Units of $\theta/5$ are $(FT^2 - SEC^2)^{-1}$

Fig. 9(c) = Units of $S_\theta(\omega)$ are $(SEC)^{-1}$

(2) The spectrum $S_s(\omega)$ may either be determined numerically from an actual wave (one-dimensional) record such as that in Figure D-2 or analytically by a formula such as the Pierson-Moskowitz equation cited on p. 25, Reference 2, or the Neuman Spectra (equation 1.28, Reference 7). In the former case, the auto correlation of the wave record is obtained

$$\Phi_z(\tau) = \lim \int_{-T}^{T} z(t)\, z(t + \tau)\, dt$$

The Fourier transform of $\Phi_z(\tau)$ is the power spectrum for the variable z.

$$S_s(\omega) = \frac{1}{\pi} \int_{-\infty}^{\infty} \Phi_z(\tau) e^{-j\omega\tau} d\tau$$

In the latter case, the amplitude of the sea spectrum is expressed for any given frequency as a function of some parameter, for example significant wave height $h_{1/3}$ (in the Pierson Moskowitz equation).

$$S_s(\omega) = (A/\omega^5) \exp(-B/\omega^4)$$

Notes for Figure D-10 - Continued

where $A = (8 \times 10^{-2})\ g^2$

$B = (33.56)\ h_{1/3}$

ω = wave frequency

or (for the Neuman spectrum) as a function of wind velocity

$$S_s(\omega) = (c/\omega^6)\ \exp\ (-2g^2/U^2\omega^2)\ \cos^2 x_m$$

$c = 32.9$ FT - SEC^{-5}

U = wind velocity

x_m = angle between wind and wave patterns.

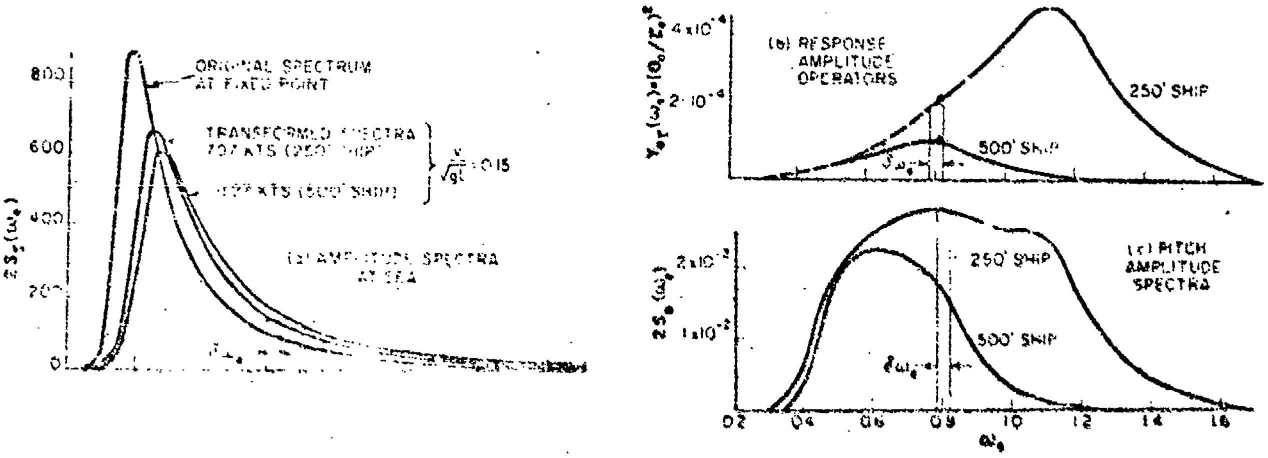


Figure D-10 Typical Pitch Responses

where θ (and η_5) is the pitch in radians and A (and η_3) are the wave amplitudes, and about 1/2 that for the 500' ship. The spectrum of Figure D-10b is the ship response amplitude operator referred to in equation D-9 above as $r(\omega)$. (Note: in the literature the various ship response amplitude operators are defined and non-dimensionalized in various ways. For example, in Reference 2, the response amplitude operator (RAO) in pitch is scaled by 2π wave amplitude/ship length:

θL/2S, L is the ships length and ζ is the wave amplitude. In the case of that reference, equation 5 is used. The difference in the curves for the 250' and 500' ships are very significant. They illustrate the general principals that apart from hull shape and weight distribution, that wave components of only certain frequencies have significant effects on ship motions. In general:

(a) Wave components of about 3/4 ship length or above have appreciable effects in pitching motions in head seas,

(b) The most severe motions result at about the ships natural pitching frequencies. The same kind of statements can be made about all ship motions components.

The total pitch ship response in a particular sea state represented by the sea state spectrum of Figure D-10a is determined by multiplying ordinate by ordinate the spectra of Figure D-10a and D-10b to obtain the spectrum of Figure D-10c. Again, it will be noted that there is a significant change in the shape of the spectra. For example, the peak amplitude of the RAO for the 250' ship is at about a frequency of 1.2, whereas the pitch amplitude spectra for the same ship is relatively flat between frequencies of 0.6 and 1.7 radians/second. The meaning of the shifting peak amplitudes in the three diagrams should be clearly understood.

(a) In the sea spectrum Figure D-10a the peak amplitude of the original spectrum is at about $\omega_o = 0.4$. The forward speeds of the two ships shifts the frequency of encounter slightly to the right since the ships are directed into head-on seas.

(b) The smooth curves of Figure D-10b represents an interpolation through an ensemble of solutions to the pitch equation of equation D-1, wherein the pitch θ has been scaled by the wave amplitude. That is

$$(\theta/\zeta)^2 = (\eta_5/a_o)^2$$

where a_o is the amplitude of the exciting wave. Each point on the smoothed RAO curve of Figure D-10b represents a single independent solution of equation D-1 (in this case the pitch equation). That is to say, the point on the faired curve $(\theta/\zeta)^2$ quoted above at an encounter frequency of 0.8 (for the 250' ship) is the η_5 (or pitch) solution to equation D-1 for the (unit) wave forcing function of

$$z/a_o = \cos\ (0.8t) \qquad \text{(Head-on)}$$

Likewise, the maximum amplitude for the 250' ship which occurs at an encounter frequency of about ω = 1.1 radians/second is the single particular η_5 solution for the particular (unit) wave

$$z/a_o = \cos\ (1.10t)$$

For each motion equation D-1 must be solved to determine separately each point on the RAO. In Reference 2, for example, solutions for pitch and heave are calculated at increments of the encounter frequency of 0.2 from 1.0 to 6.4.

(c) The pitch amplitude spectra Figure D-10c is for each frequency, the product of the transformed sea spectra (in terms of encounter frequency) and the RAO of Figure D-10b. However, what is important to realize is that the pitch spectrum ($s_\theta(\omega)$ of Figure D-10c is itself a spectrum of exactly the same statistical nature as Figure D-10a. The spectral curve tells us nothing directly about the expected amplitudes of pitching and nothing whatsoever concerning the frequencies at which these expected amplitudes might occur. Statistically, the expected amplitudes are related to the total area under the pitch amplitude spectra, Figure D-10c. Thus for the total energy

$$E_\theta = \int_0^\infty S_\theta(\omega)\,d\omega = 1/2 \int_0^\infty 2\,S_\theta(\omega)\,d\omega$$

statistical theory states that for a typical "Rayleigh" distribution, the average amplitude θ_n, "significant" (or average of 1/3 largest) $\theta_{1/3}$, and average of the 1/10th highest amplitudes $\theta_{1/10}$, are given by the expressions

$$\theta_{av} = 1.253 \quad E_\theta$$

$$\theta_{1/3} = 2.000 \quad E_\theta$$

$$\theta_{1/10} = 2.546 \quad E_\theta$$

Thus, in the case quoted in Figure D-10, the total "energy" in the curve for the 250' ship from $0 \leq \omega \leq \infty$ is about

$$2.5 \times 10^{-2} \quad (SEC^3\text{-}FT^2)^{-1} \quad \text{Thus,}$$

$$\theta_{av} = \pm 1.8°$$

$$\theta_{1/3} = \pm 2.9°$$

$$\theta_{1/10} = \pm 3.7°$$

Although this fact has been referred to with varying degrees of emphasis several times in the foregoing discussion it is considered very important in view of what will follow to enlarge upon it again:

Although the various "statistical" amplitudes referred to above ("average", "significant" or "1/10th highest") are functions of the total area of the energy curve, this method provides no information to associate these amplitudes with any specific frequency. Although our mathematical intuition assures us that there is no other way for it to be, it is nonetheless a feeling of somehow being cheated that overcomes us when we review the three sets of curves in Figure D-10. The curve of Figure D-10b is composed of a faired interpolation of points, each of which as a solution of one of the equations of the set equation D-1 is a solution which combines both amplitude and frequency (as well as phase lag) information. For example, as quoted above, at an encounter frequency of 0.8, where $(\theta/L)^2 = 2 \times 10^{-4}$, this ship pitches about

$$\theta = 0.815°/FT \text{ of wave}$$

That is to say that for a 2' wave of the form

$$z = 2 \cos 0.8t$$

The ship would pitch according to the expression

$$\eta_5 = 0.815 (\cos 0.8t + \varepsilon_5)$$

(where ε_5 although determined by the solution of equation D-2 is not included in the data of Figure D-10b). However, in the generation of Figure D-10c, both the frequency and phase information of solution D-2 is discarded, and amplitudes of given dimensions (such as "average" or "significant" or "average of 1/10th highest") or the probability of an amplitude of any given height is determined from the total integrated area of the $S_\theta(\omega)$ curve. For example, statistical theory for this type of distribution (the "Rayleigh" distribution) states that the probability that the amplitude θ, a given response will exceed an amplitude θ, given height θ_1, is

$$P(\theta > \theta_1) = \exp\left(-\theta_1^2/2E\right)$$

Since the "significant" amplitude "average of the 1/3rd highest) for a Rayleigh solution is

$$\theta_{1/3} = 2.00 \quad E_\theta$$

where

$$E = \int_0^\infty S_\theta(\omega)\, d_\omega$$

for any sufficiently large number N such that $N = P(\theta_N > \theta_{1/3})^{-1}$ the most probable largest pitching amplitude θ_N is

$$\theta_N = \theta_{1/3} \quad \ln N \; / \quad 2$$

No similar information is provided from Figure D-10c for the most probable frequency or range of frequencies for which a given amplitude may occur.

APPENDIX E

COMPILATION OF HARRIER DATA

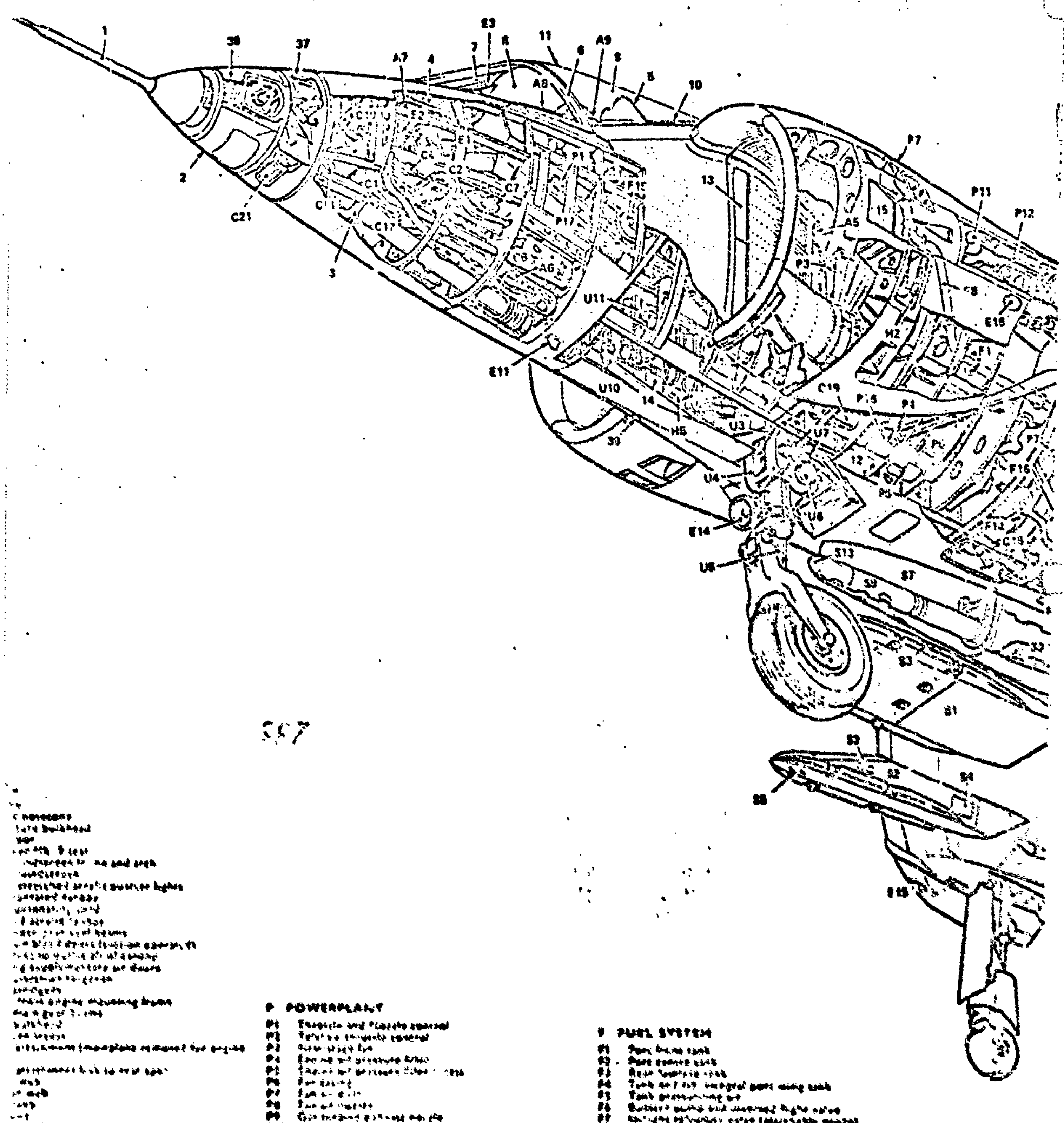
COMPILATION OF HARRIER DATA

The data on the Harrier GR Mark 1 aircraft which follows was received by CADCOM after the conclusion of the project described in this report. It was furnished by Dr. Bernard H. Carson of the Office of Naval Research, London.

CADCOM includes it herein strictly for information purposes and makes no representations about its accuracy or completeness.

H HYDRAULICS

- **H1** Nitrogen bottle u/c emergency operation
- **H2** General service system hand pump and pressure gauge
- **H3** Ground servicing points No. 1 system
- **H4** Reservoir No. 1 system
- **H5** Accumulator, nose wheel steering



P POWERPLANT

- **P1** Throttle and [illegible] control
- **P2** [illegible]
- **P3** [illegible]
- **P4** [illegible]
- **P5** [illegible]
- **P6** [illegible]
- **P7** [illegible]
- **P8** [illegible]
- **P9** [illegible]
- **P10** [illegible]
- **P11** [illegible]
- **P12** [illegible] (engine bleed)
- **P13** [illegible]
- **P14** [illegible]
- **P15** [illegible]
- **P16** [illegible]
- **P17** [illegible]
- **P18** [illegible]
- **P19** [illegible]
- **P20** [illegible]
- **P21** [illegible]
- **P22** [illegible]

F FUEL SYSTEM

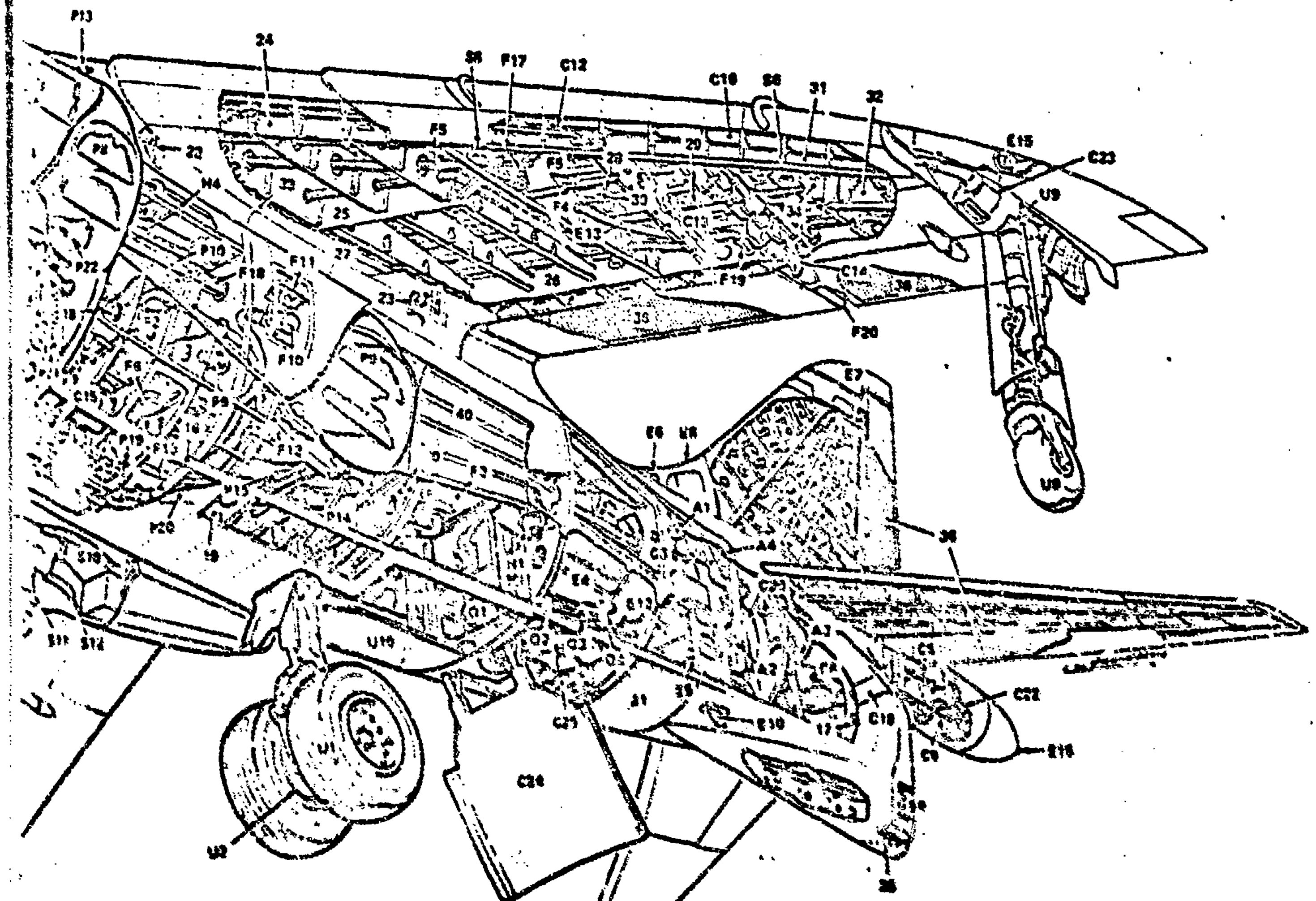
- **F1** [illegible]
- **F2** Port centre tank
- **F3** [illegible]
- **F4** [illegible] integral port wing tank
- **F5** Tank pressurising air
- **F6** [illegible]
- **F7** [illegible]
- **F8** [illegible]
- **F9** [illegible]
- **F10** [illegible]
- **F11** [illegible]
- **F12** [illegible]
- **F13** [illegible]
- **F14** [illegible]
- **F15** [illegible]
- **F16** [illegible]
- **F17** [illegible]
- **F18** [illegible]
- **F19** [illegible]
- **F20** [illegible]

U1 Rigid live-axle mounted mainwheel
U2 Multi-disc brakes
U3 Retraction jack
U4 Pre-shortening nose-gear leg
U5 Liquid Spring unit
U6 Steering motor plus or minus 45 deg. (170 deg. disengaged)
U7 Steering control valve
U8 Outrigger wheels (90 deg. castor inwards only)
U9 Leg pivot
U10 Pre-closing door
U11 Door jacks

E1 Nav/attack display
E2 Nav/attack computer
E3 Sight and head-up display
E4 Shockproof equipment tray with integral cooling duct carries Tacan, IFF, voice recorder, top temp amplifier. Lower tray air data, nav/attack equipment
E5 Transformer-rectifier unit
E6 HF Tuner
E7 VHF aerial
E8 HF notch aerial
E9 IFF notch aerial
E10 UHF stand-by aerial
E11 Tacan
E12 Batteries, 28v 25Ah
E13 Cable duct
E14 Landing lamp
E15 Nav lights
E16 Ground intercom

C CONTROL SYSTEMS

C1 Rudder input from pedals
C2 Rudder quadrant
C3 Rudder cable tensioner
C4 Rudder centring unit
C5 Linkage from rudder to yaw-reaction nozzle
C6 Tailplane control input from column
C7 Tailplane quadrant
C8 Tandem tailplane jack
C9 Linkage to pitch reaction nozzle
C10 Pitch spring feel
C11 Pitch Q-feel
C12 Aileron control rod
C13 Tandem aileron jack with autostabiliser
C14 Aileron offset hinge
C15 Reaction control bleed air supply shut-off v (open after 15 deg. nozzle rotation)
C16 Duct to roll-reaction valve
C17 Duct to pitch-reaction valve
C18 Duct to pitch and yaw-reaction valve
C19 Control cable and pipe run duct
C20 Rudder and tailplane cables
C21 Pitch reaction valve
C22 Pitch and yaw reaction valve
C23 Roll reaction valve
C24 Airbrake
C25 Airbrake jack



S STORES

S1 [illegible]
S2 [illegible]
S3 [illegible] cartridge loading
S4 [illegible]
S5 [illegible]
S6 [illegible]
S7 [illegible]
S8 [illegible]
S9 [illegible]
S10 [illegible]
S11 [illegible]
S12 [illegible]
S13 [illegible]

A AIR SYSTEM

A1 [illegible]
A2 Cold air [illegible]
A3 [illegible]
A4 [illegible]
A5 [illegible]
A6 [illegible]
A7 [illegible]
A8 [illegible]
A9 Canopy [illegible] air

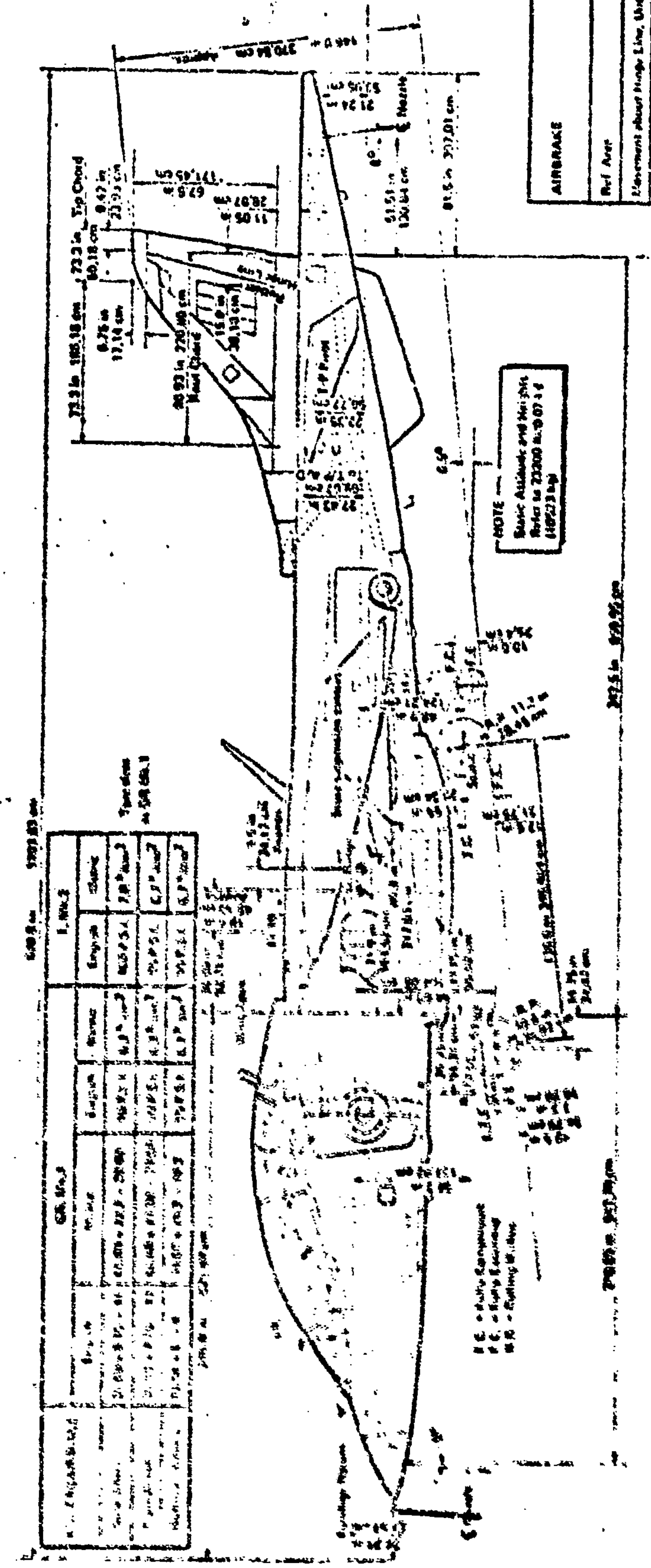
O OXYGEN

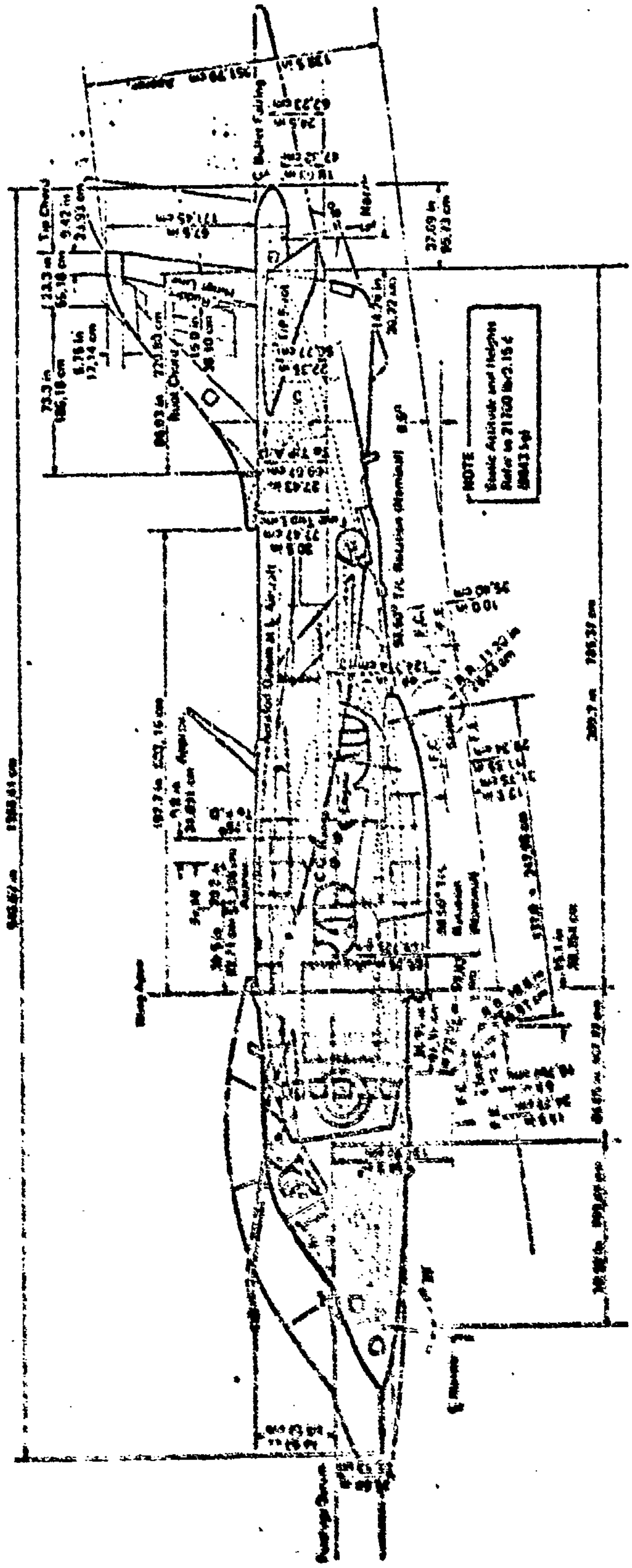
O1 [illegible] container
O2 [illegible]
O3 Ground charging [illegible]
O4 Pressure gauge

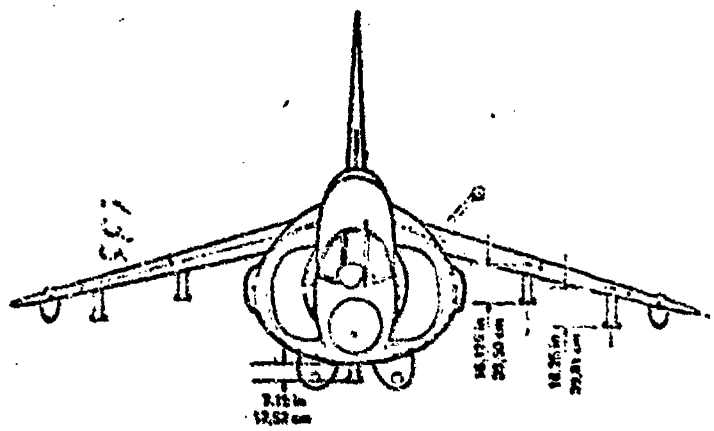
Hawker Siddeley

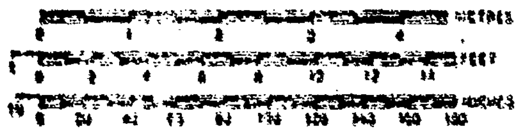
Harrier

AIRBRAKE	English	Metric
Ref Area	8.5 ft²	0.790 m²
Movement about Hinge Line, Undercarriage Up	66°	
Movement about Hinge Line, Undercarriage Down	25°	

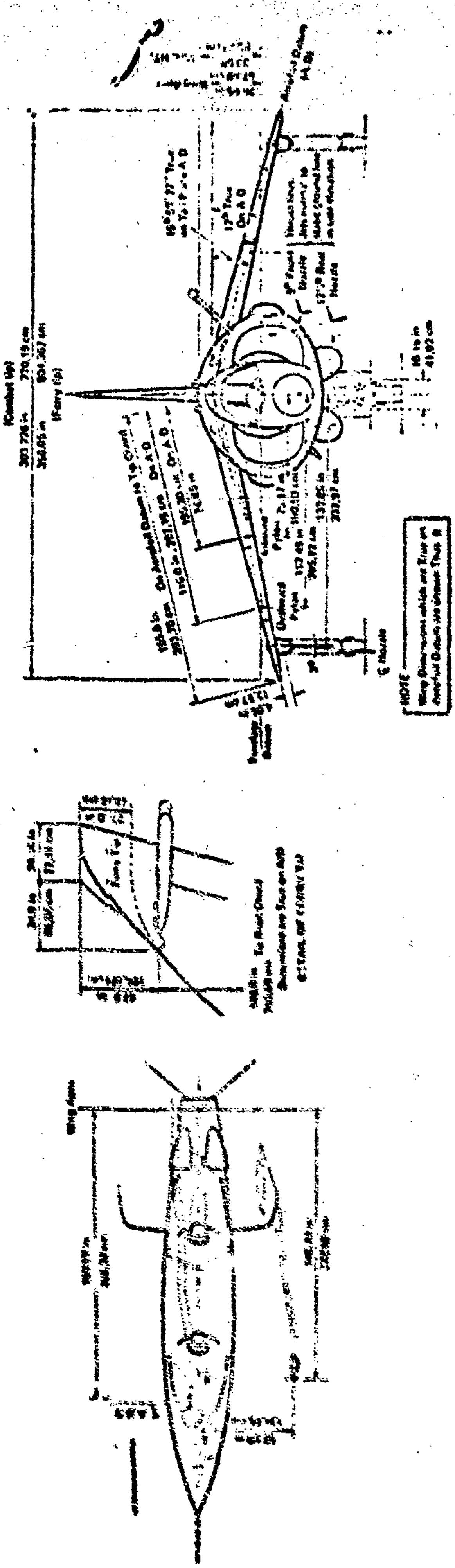


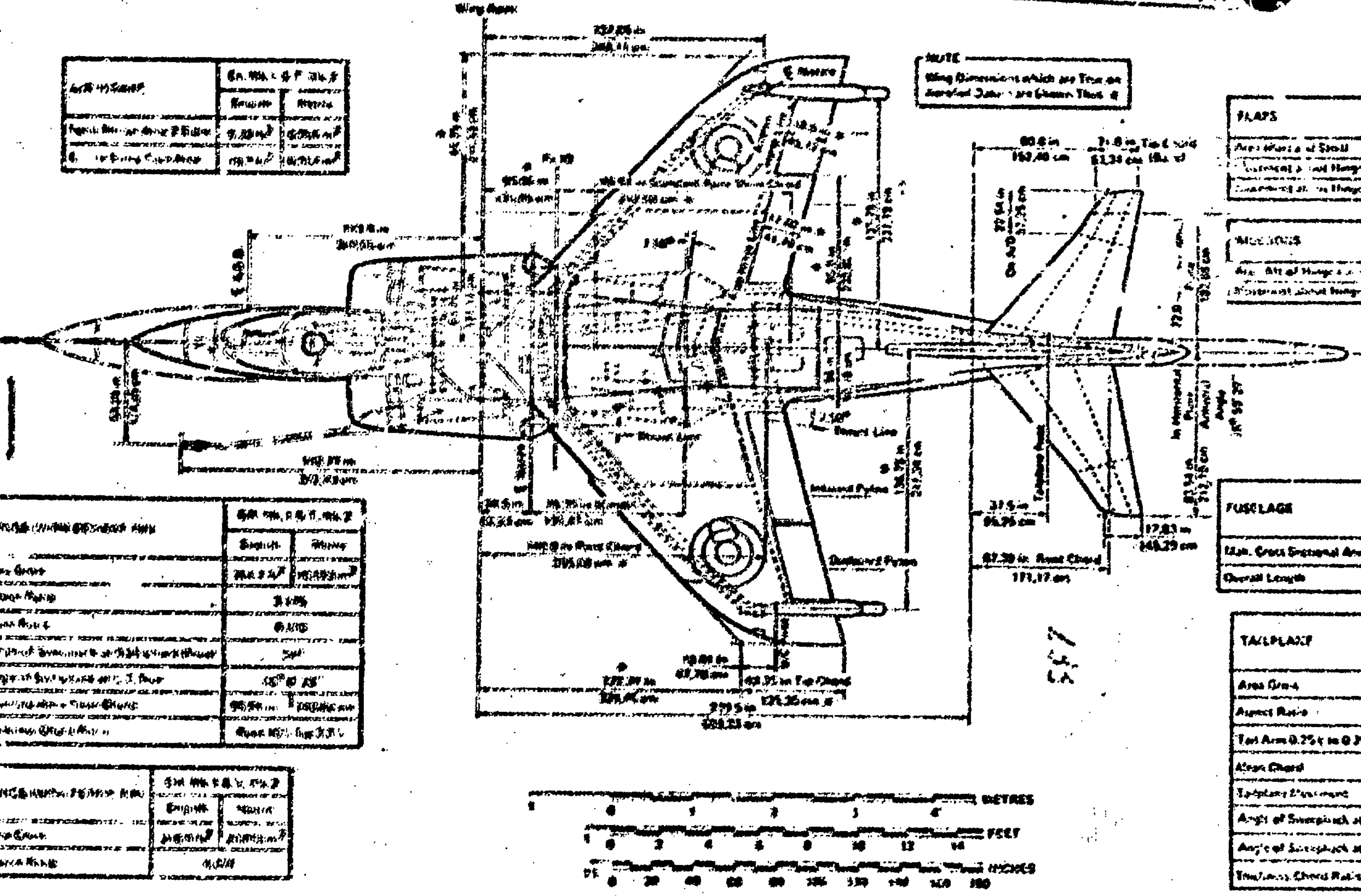






FIN AND RUDDER	GR. Mk. 1		T. Mk. 2	
	English	Metric	English	Metric
Nett Area Excluding Fuselage	[illegible]	[illegible]	[illegible]	[illegible]
Fin Arm 0.25 c to 0.25 c Wing	[illegible]	[illegible]	[illegible]	[illegible]
Angle of Sweepback at L/E	[illegible]		[illegible]	
Angle of Sweepback at 0.25 Chord	[illegible]		[illegible]	
Rudder Area Aft of Hinge Line	[illegible]	[illegible]	[illegible]	[illegible]
Rudder Movement Normal to Hinge Line	±15°		±15°	





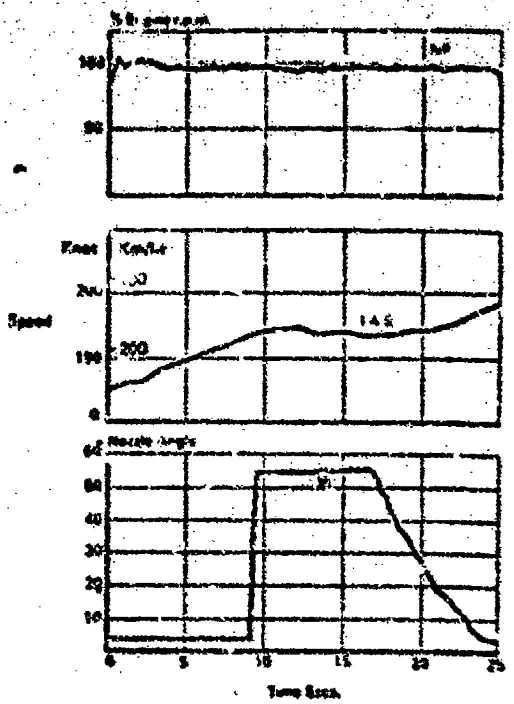
FLAPS	Gr. Mk.1 & T. Mk.2	
	English	Metric
Area Aft of Hinge Line and Shroud	13.9 ft²	1.29 m²
Movement about Hinge Line (Take Off Setting)	50° Nose Down	
Movement about Hinge Line (Intermediate Setting)	17° Nose Down	

AILERONS	GR. Mk.1 & T. Mk.2	
	English	Metric
Area Aft of Hinge Line, Port and Stbd	10.54 ft²	0.979 m²
Movement about Hinge Line	High Speed ± 9° 24'	Low Speed ± 12°

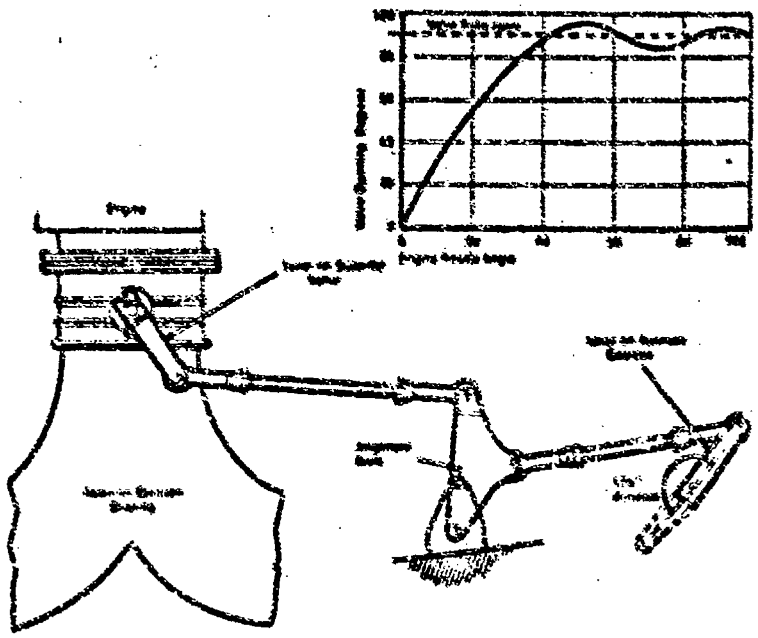
FUSELAGE	Gr. Mk.1		T. Mk.2	
	English	Metric	English	Metric
Max. Cross Sectional Area	20.31 ft²	2.886 m²	22.00 ft²	2.047 m²
Overall Length	45.55 ft	1264.34 cm	55.97 ft	1705.75 cm

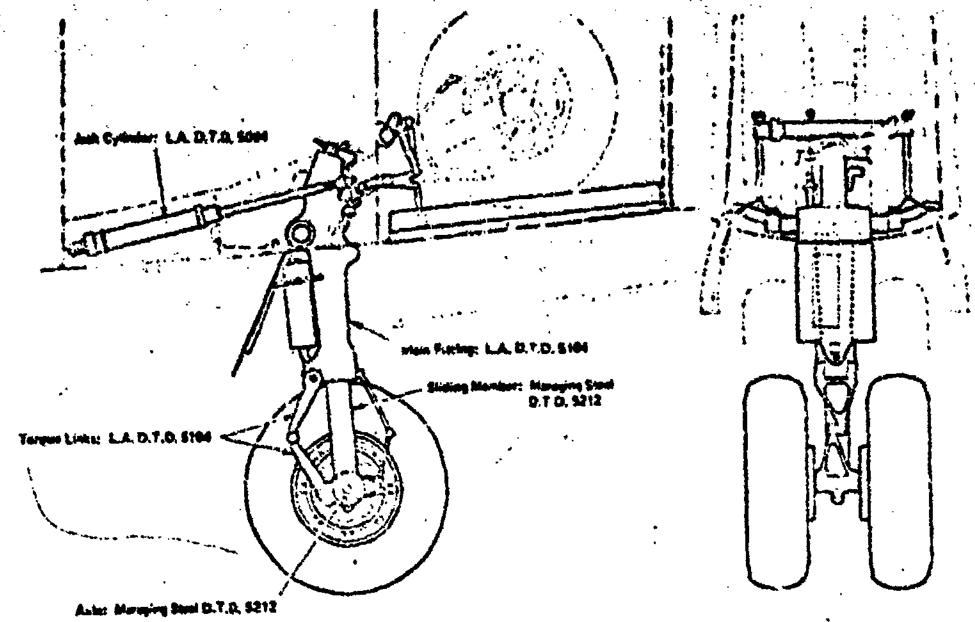
TAILPLANE	Gr. Mk.1 & T. Mk.2	
	English	Metric
Area Gross	47.54 ft²	4.417 m²
Aspect Ratio	4.073	
Tail Arm 0.25 c to 0.25 c Wing	[illegible]	[illegible]
Mean Chord	3.414 ft	104.1 cm
Tailplane Movement	[illegible]	16° 25'
Angle of Sweepback at 0.25 Chord (True Inboard)	32° [illegible] 26'	
Angle of Sweepback at L.E. (True Inboard)	2[illegible]° 43' 7'	
Thickness Chord Ratio	[illegible]	

Leading Particulars

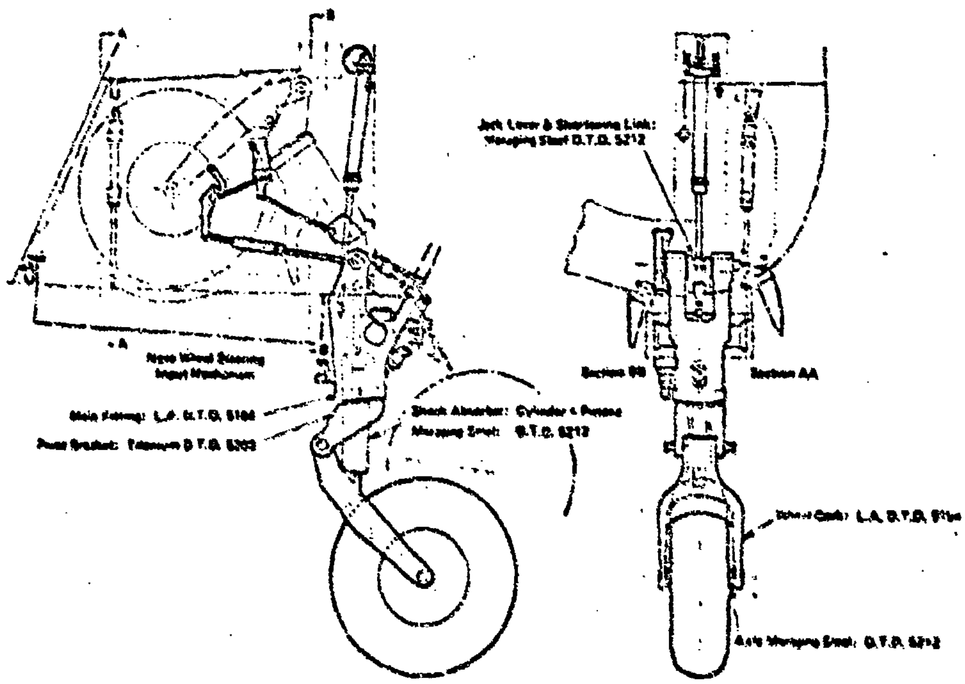


Typical time history of a short take-off.

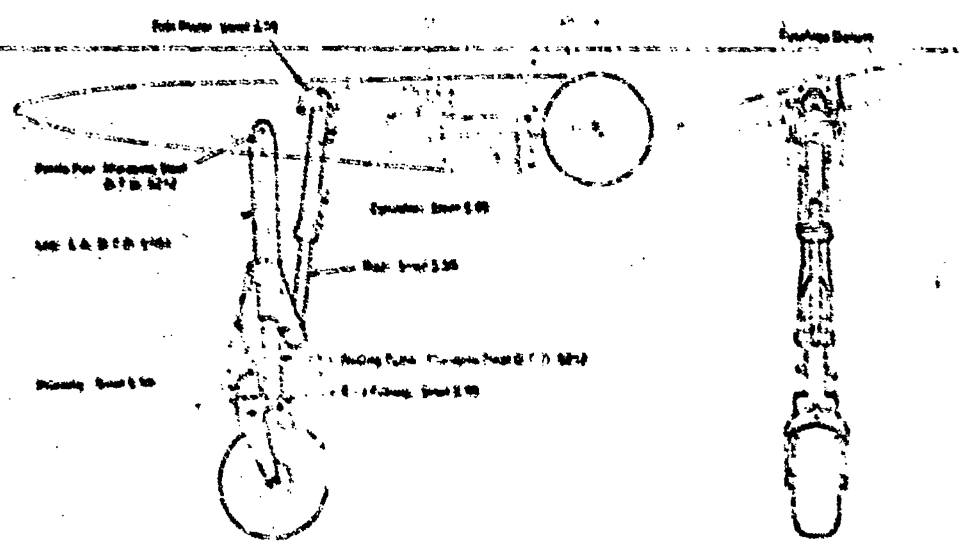




-Design of the main undercarriage, a twin-wheeled single telescopic oleo pneumatic strut.

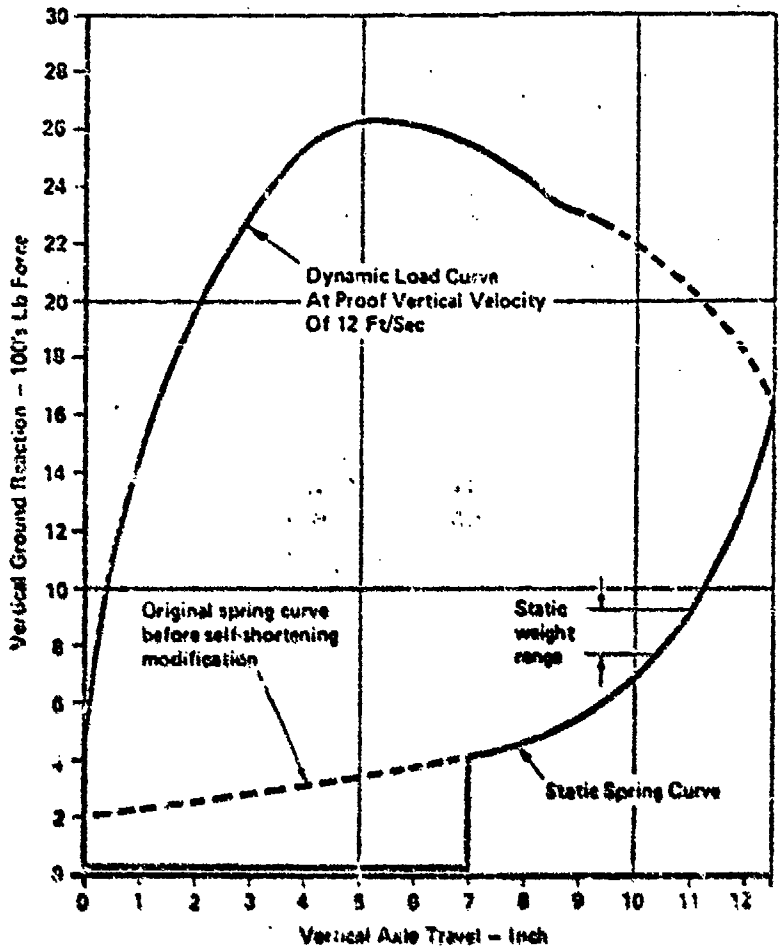


-Design of the nose undercarriage.

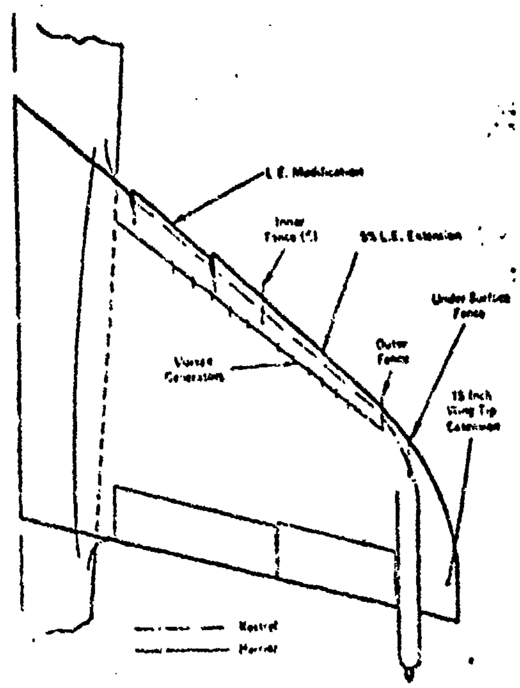


-Design of the outrigger undercarriage.

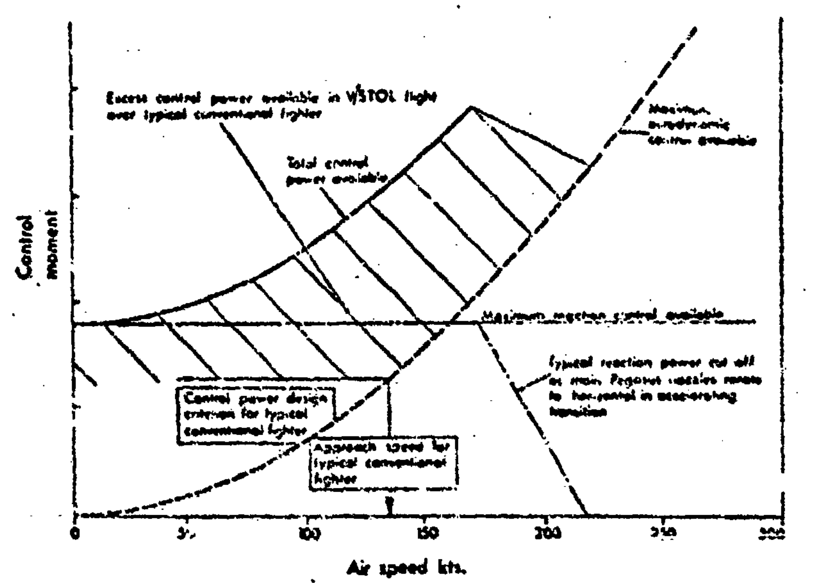
Main Leg Characteristics



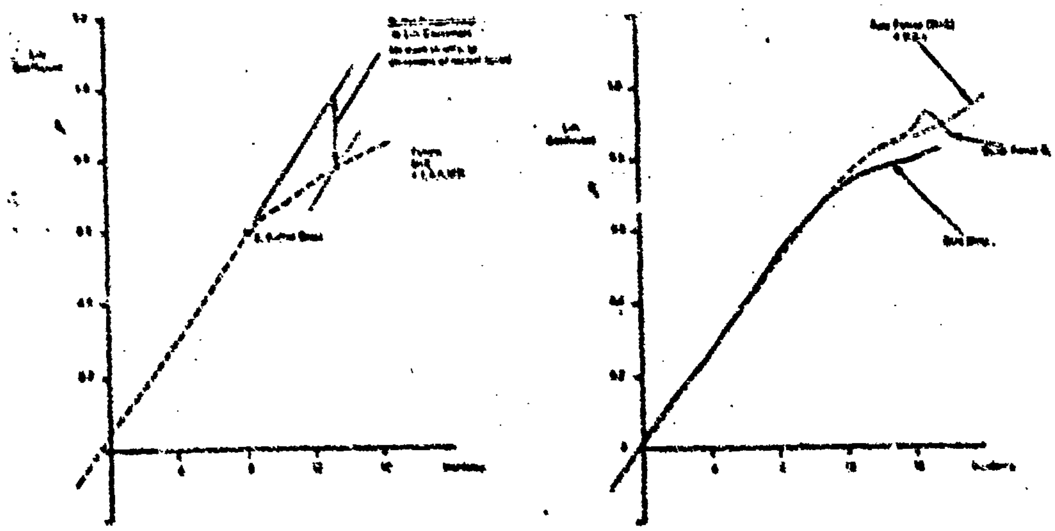
-The main undercarriage spring curve.



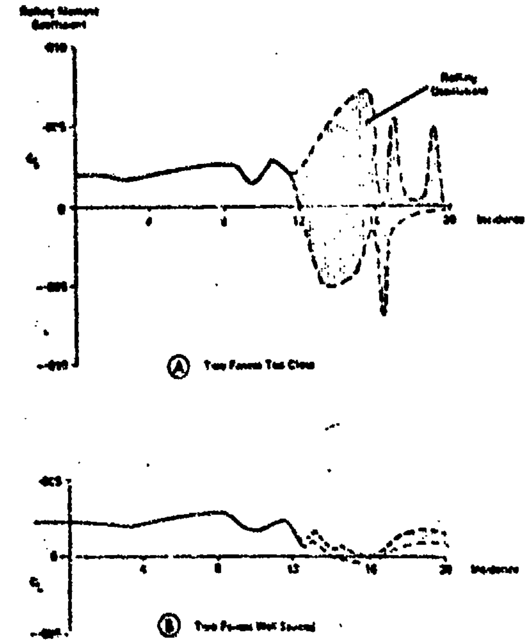
Planform of Harrier wing, showing Kestrel basis.



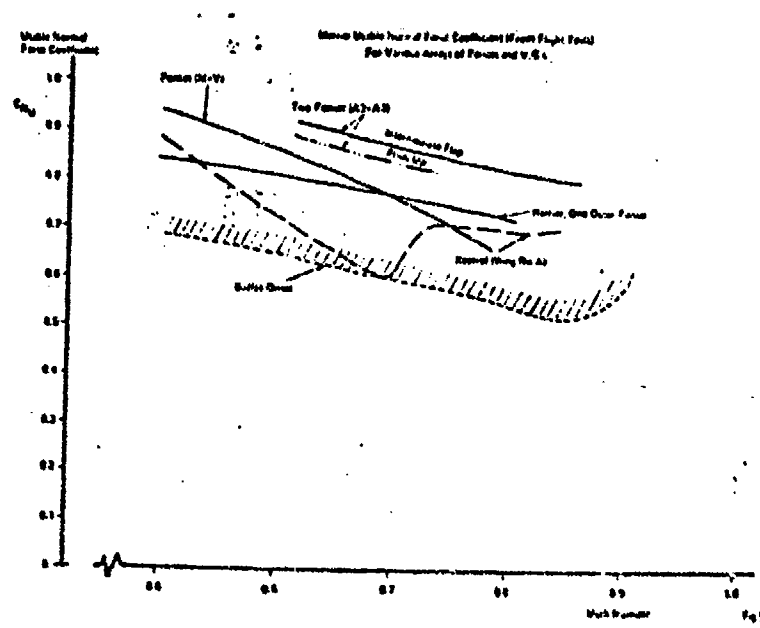
-Control power available in relation to airspeed.



Typical lift curves (a) buffet relationship, (b) effects of fences.

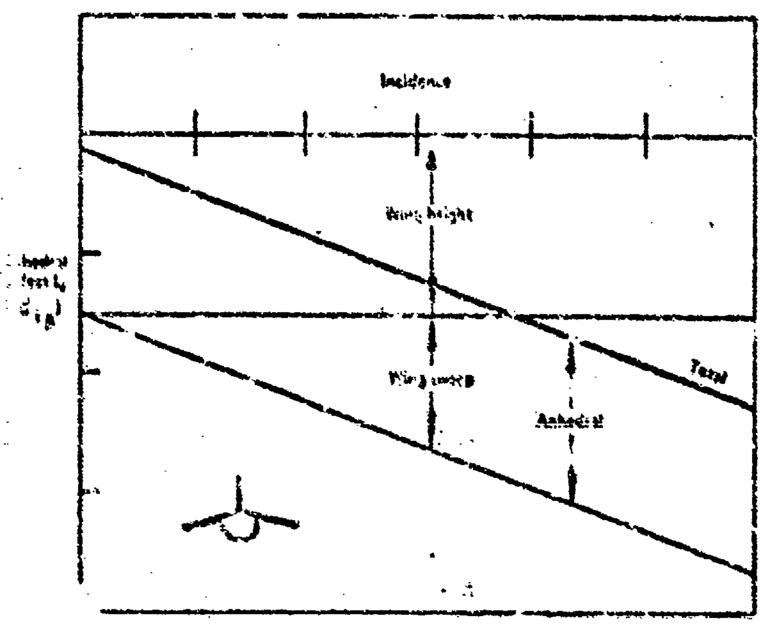


Roll unsteadiness with
two fences:
(a) too close
(b) properly spaced.

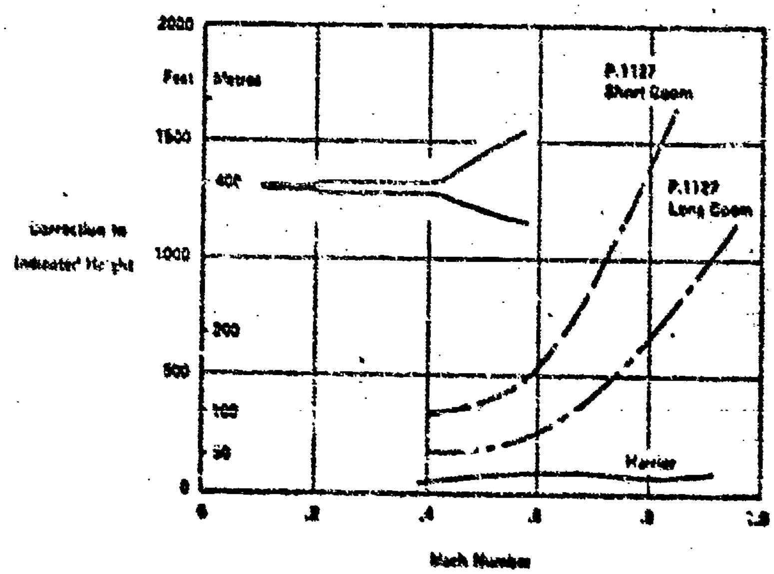


Typical usable normal-
force coefficients:
various fences and flaps
on Harrier.

STABILITY AND CONTROL



The various contributions needed to bring the total dihedral effect to an acceptable level.



The position errors achieved at low altitude with a short, light weight pitot-static probe compared with an uncompensated probe of the same length.